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Attorneys for Plaintiff AuthenTec, Inc.

UNITED STATES DISTRICT COURT

NORTHERN DISTRICT OF CALIFORNIA

SAN JOSE DIVISION

AuthenTec, Inc., a Delaware Corporation, Plaintiff, vs. Atrua Technologies, Inc., a California Corporation, Defendant.	Case No. C08 01423 (HRL) **FIRST AMENDED COMPLAINT FOR PATENT INFRINGEMENT** **DEMAND FOR JURY TRIAL**

Plaintiff AuthenTec, Inc. ("AuthenTec") alleges the following in support of its First Amended Complaint for Patent Infringement and Demand for Jury Trial ("First Amended Complaint") against Defendant Atrua Technologies, Inc. ("Atrua"):

PARTIES

1. AuthenTec is a Delaware corporation having a principal place of business at 709 South Harbor City Boulevard, Melbourne, Florida 32901.

2. On information and belief, Atrua is a California corporation having a principal place of business at 1696 Dell Avenue, Campbell, California 95008.

JURISDICTION

3. This Court has subject matter jurisdiction over this action pursuant to 28 U.S.C. §§ 1331, 1338(a) because this action arises under the patent laws of the United States, including 35 U.S.C. §§ 101, *et seq.* and 271, *et seq*.

4. This Court has personal jurisdiction over Atrua because AuthenTec is informed and believes that Atrua is incorporated in California and maintains its corporate headquarters in Campbell, California, which is located in this District.

VENUE

5. Venue is proper in this judicial District under 28 U.S.C. §§ 1391(b) and 1400(b) because AuthenTec is informed and believes that a substantial part of the events giving rise to this claim occurred in this District, and Atrua has a regular and established place of business in this District.

INTRADISTRICT ASSIGNMENT

6. This action is an Intellectual Property Action that arises in Santa Clara County. Pursuant to Civil L.R. 3-2(c) and (e), this action should be assigned to the San Jose Division.

COUNT 1

(Infringement of U.S. Patent No. 5,862,248)

7. Paragraphs 1 through 6 of the Complaint set forth above are incorporated herein by reference.

8. On January 19, 1999, United States Patent No. 5,862,248 ("the '248 Patent") entitled "Integrated Circuit Device Having an Opening Exposing the Integrated Circuit Die and Related Methods" was duly and legally issued to Matthew M. Salatino, S. James Studebaker, and Nicolaas W. VanVonno. AuthenTec is the owner of all rights and interest in and to the '248 Patent by assignment. A true and correct copy of the '248 Patent is attached hereto as Exhibit A.

9. Upon information and belief, Atrua has infringed and continues to infringe under 35 U.S.C. § 271 the ‘248 Patent. The infringing acts include, but are not limited to, importing, selling, and offering for sale in the United States biometric products, systems, and devices, including fingerprint sensors, that are covered by one or more claims of the ‘248 Patent, and inducing and contributing to the infringement of such claims. Atrua has been offering and continues to offer for sale such products, systems, and devices without the authorization of AuthenTec.

10. Atrua’s acts of infringement have caused damage to AuthenTec in an amount subject to proof at trial. Under 35 U.S.C. § 284, AuthenTec is entitled to recover from Atrua the damages sustained by AuthenTec as a result of Atrua’s infringement of the ‘248 Patent. Atrua’s infringement of AuthenTec’s exclusive rights under the ‘248 Patent will continue to damage AuthenTec’s business, causing it irreparable harm, for which there is no adequate remedy at law, unless enjoined by this Court under 35 U.S.C. § 283.

11. Upon information and belief, Atrua’s infringement of the ‘248 Patent has been willful and deliberate, and entitles AuthenTec to increased damages under 35 U.S.C. § 284 and attorneys’ fees and costs under 35 U.S.C. § 285.

COUNT 2

(Infringement of U.S. Patent No. 6,667,439)

12. Paragraphs 1 through 11 of the Complaint set forth above are incorporated herein by reference.

13. On December 23, 2003, United States Patent No. 6,667,439 (“the ‘439 Patent”) entitled “Integrated Circuit Package Including Opening Exposing Portion of an IC” was duly and legally issued to Matthew M. Salatino and Patrick O. Weber. AuthenTec and Hestia Technologies, Inc. are the owners of all rights and interest in and to the ‘439 Patent by assignment. A true and correct copy of the ‘439 Patent is attached hereto as Exhibit B.

14. Upon information and belief, Atrua has infringed and continues to infringe under 35 U.S.C. § 271 the ‘439 Patent. The infringing acts include, but are not limited to, importing, selling, and offering for sale in the United States biometric products, systems, and devices, including

fingerprint sensors, that are covered by one or more claims of the '439 Patent, and inducing and contributing to the infringement of such claims. Atrua has been offering and continues to offer for sale such products, systems, and devices without the authorization of AuthenTec.

15. Atrua's acts of infringement have caused damage to AuthenTec in an amount subject to proof at trial. Under 35 U.S.C. § 284, AuthenTec is entitled to recover from Atrua the damages sustained by AuthenTec as a result of Atrua's infringement of the '439 Patent. Atrua's infringement of AuthenTec's exclusive rights under the '439 Patent will continue to damage AuthenTec's business, causing it irreparable harm, for which there is no adequate remedy at law, unless enjoined by this Court under 35 U.S.C. § 283.

16. Upon information and belief, Atrua's infringement of the '439 Patent has been willful and deliberate, and entitles AuthenTec to increased damages under 35 U.S.C. § 284 and attorneys' fees and costs under 35 U.S.C. § 285.

COUNT 3

(Infringement of U.S. Patent No. 5,940,526)

17. Paragraphs 1 through 16 of the Complaint set forth above are incorporated herein by reference.

18. On August 17, 1999, United States Patent No. 5,940,526 ("the '526 Patent") entitled "Electric Field Fingerprint Sensor Having Enhanced Features and Related Methods" was duly and legally issued to Dale R. Setlak, Nicolaas W. VanVonno, Rex Lowther, and Dave Gebauer. AuthenTec is the owner of all rights and interest in and to the '526 Patent by assignment. A true and correct copy of the '526 Patent is attached hereto as Exhibit C.

19. Upon information and belief, Atrua has infringed and continues to infringe under 35 U.S.C. § 271 the '526 Patent. The infringing acts include, but are not limited to, importing, selling, and offering for sale in the United States biometric products, systems, and devices, including fingerprint sensors, that are covered by one or more claims of the '526 Patent, and inducing and contributing to the infringement of such claims. Atrua has been offering and continues to offer for sale such products, systems, devices, processes, and methods without the authorization of AuthenTec.

20. Atrua's acts of infringement have caused damage to AuthenTec in an amount subject to proof at trial. Under 35 U.S.C. § 284, AuthenTec is entitled to recover from Atrua the damages sustained by AuthenTec as a result of Atrua's infringement of the '526 Patent. Atrua's infringement of AuthenTec's exclusive rights under the '526 Patent will continue to damage AuthenTec's business, causing it irreparable harm, for which there is no adequate remedy at law, unless enjoined by this Court under 35 U.S.C. § 283.

21. Upon information and belief, Atrua's infringement of the '526 Patent has been willful and deliberate, and entitles AuthenTec to increased damages under 35 U.S.C. § 284 and attorneys' fees and costs under 35 U.S.C. § 285.

COUNT 4

(Infringement of U.S. Patent No. 5,963,679)

22. Paragraphs 1 through 21 of the Complaint set forth above are incorporated herein by reference.

23. On October 5, 1999, United States Patent No. 5,963,679 ("the '679 Patent") entitled "Electric Field Fingerprint Sensor Apparatus and Related Methods" was duly and legally issued to Dale R. Setlak. AuthenTec is the owner of all rights and interest in and to the '679 Patent by assignment. A true and correct copy of the '679 Patent is attached hereto as Exhibit D.

24. Upon information and belief, Atrua has infringed and continues to infringe under 35 U.S.C. § 271 the '679 Patent. The infringing acts include, but are not limited to, importing, selling, and offering for sale in the United States biometric products, systems, and devices, including fingerprint sensors, that are covered by one or more claims of the '679 Patent, and inducing and contributing to the infringement of such claims. Atrua has been offering and continues to offer for sale such products, systems, and devices without the authorization of AuthenTec.

25. Atrua's acts of infringement have caused damage to AuthenTec in an amount subject to proof at trial. Under 35 U.S.C. § 284, AuthenTec is entitled to recover from Atrua the damages sustained by AuthenTec as a result of Atrua's infringement of the '679 Patent. Atrua's infringement of AuthenTec's exclusive rights under the '679 Patent will continue to damage AuthenTec's business,

causing it irreparable harm, for which there is no adequate remedy at law, unless enjoined by this Court under 35 U.S.C. § 283.

26. Upon information and belief, Atrua's infringement of the '679 Patent has been willful and deliberate, and entitles AuthenTec to increased damages under 35 U.S.C. § 284 and attorneys' fees and costs under 35 U.S.C. § 285.

COUNT 5

(Infringement of U.S. Patent No. 6,259,804)

27. Paragraphs 1 through 26 of the Complaint set forth above are incorporated herein by reference.

28. On July 10, 2001, United States Patent No. 6,259,804 ("the '804 Patent") entitled "Fingerprint Sensor with Gain Control Features and Associated Methods" was duly and legally issued to Dale R. Setlak, John Cornett, Brian Kilgore, Daryl Williams, and Dave Gebauer. AuthenTec is the owner of all rights and interest in the '804 Patent by assignment. A true and correct copy of the '804 Patent is attached hereto as Exhibit E.

29. Upon information and belief, Atrua has infringed and continues to infringe under 35 U.S.C. § 271 the '804 Patent. The infringing acts include, but are not limited to, importing, selling, and offering for sale in the United States biometric products, systems, and devices, including fingerprint sensors, that are covered by one or more claims of the '804 Patent, and inducing and contributing to the infringement of such claims. Atrua has been offering and continues to offer for sale such products, systems, and devices without the authorization of AuthenTec.

30. Atrua's acts of infringement have caused damage to AuthenTec in an amount subject to proof at trial. Under 35 U.S.C. § 284, AuthenTec is entitled to recover from Atrua the damages sustained by AuthenTec as a result of Atrua's infringement of the '804 Patent. Atrua's infringement of AuthenTec's exclusive rights under the '804 Patent will continue to damage AuthenTec's business, causing it irreparable harm, for which there is no adequate remedy at law, unless enjoined by this Court under 35 U.S.C. § 283.

31. Upon information and belief, Atrua's infringement of the '804 Patent has been willful and deliberate, and entitles AuthenTec to increased damages under 35 U.S.C. § 284 and attorneys' fees and costs under 35 U.S.C. § 285.

PRAYER FOR RELIEF

WHEREFORE, AuthenTec respectfully requests that this Court enter judgment against Atrua as follows:

a) For judgment that Atrua has infringed and continues to infringe the '248 Patent, the '439 Patent, '526 Patent, the '679 Patent, and the '804 Patent;

b) For preliminary and permanent injunctions under 35 U.S.C. § 283 against Atrua and its directors, officers, employees, agents, servants, subsidiaries, parents, successors, assigns, attorneys, and all persons acting in concert, on behalf of, in joint venture with, or in partnership with Atrua from further infringing acts;

c) For damages to be paid by Atrua adequate to compensate AuthenTec for Atrua's infringement, including interests, costs, and disbursements as the Court may deem appropriate under 35 U.S.C. § 284;

d) For judgment finding that Atrua's infringement was willful and deliberate, entitling AuthenTec to increased damages under 35 U.S.C. § 284;

e) For judgment finding this to be an exceptional case, and awarding AuthenTec attorneys' fees and costs under 35 U.S.C. § 285; and

f) For such other and further relief at law and in equity as the Court may deem just and proper.

Dated: April 25, 2008

Respectfully submitted,

HOWREY LLP

By: *_/s/ Denise M. De Mory_*
Denise M. De Mory
Attorneys for Plaintiff
AuthenTec, Inc.

DEMAND FOR JURY TRIAL

AuthenTec hereby demands a trial by jury on all issues set forth in its Complaint for Patent Infringement pursuant to Fed. R. Civ. P. 38 and Civ. L.R. 3-6.

Dated: April 25, 2008

Respectfully submitted,

HOWREY LLP

By: *_____/s/ Denise M. De Mory_____*
Denise M. De Mory
Attorneys for Plaintiff
AuthenTec, Inc.

EXHIBIT A

US005862248A

United States Patent [19]

Salatino et al.

[11] **Patent Number: 5,862,248**

[45] **Date of Patent: Jan. 19, 1999**

[54] **INTEGRATED CIRCUIT DEVICE HAVING AN OPENING EXPOSING THE INTEGRATED CIRCUIT DIE AND RELATED METHODS**

[75] Inventors: **Matthew M. Salatino**, Satellite Beach; **S. James Studebaker**, Palm Bay; **Nicolaas W. VanVonno**, Melbourne, all of Fla.

[73] Assignee: **Harris Corporation**, Palm Bay, Fla.

[21] Appl. No.: **671,430**

[22] Filed: **Jun. 27, 1996**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 592,472, Jan. 26, 1996.

[51] **Int. Cl.**[6] **G06K 9/28**

[52] **U.S. Cl.** **382/124**; 382/312; 438/127

[58] **Field of Search** 382/116, 124, 382/125, 126, 127, 312, 313, 314, 315; 356/71; 438/15, 51, 55, 64, 60, 112, 116, 119, 124, 126, 127; 324/348, 457; 340/825.34; 361/181; 264/272.17; 364/468.28; 427/96; 399/3; 348/272, 294, 311, 306

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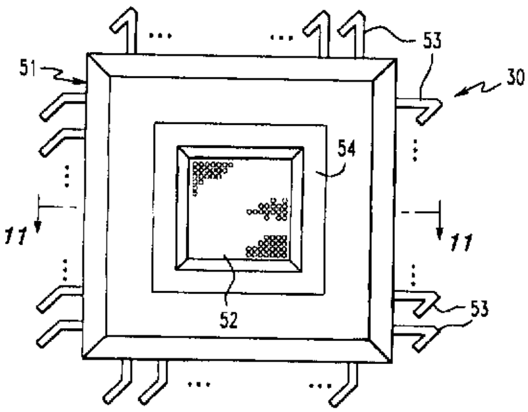
Primary Examiner—Leo H. Boudreau
Assistant Examiner—Brian P. Werner
Attorney, Agent, or Firm—Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A.

[57] **ABSTRACT**

An integrated circuit device, such as a fingerprint sensing device, includes an integrated circuit die, a body of encapsulating material surrounding the integrated circuit die and having an opening therein exposing a portion of the integrated circuit die, and an electrically conductive member or frame being mounted to the body of encapsulating material adjacent the opening therein. The electrically conductive member may preferably be positioned so as to define at least a portion of a frame for the opening in the body of encapsulating material. The electrically conductive member may be adhesively secured to the integrated circuit die. Accordingly, the adhesive and electrically conductive member may serve as a seal to the interface between the body of encapsulating material and the die. The electrically conductive member may define a frame that surrounds a body of removable material during an intermediate stage in manufacturing. More particularly, the body of removable material and its frame may be positioned on the integrated circuit die while plastic is injection molded to encapsulate the asembly.

39 Claims, 6 Drawing Sheets



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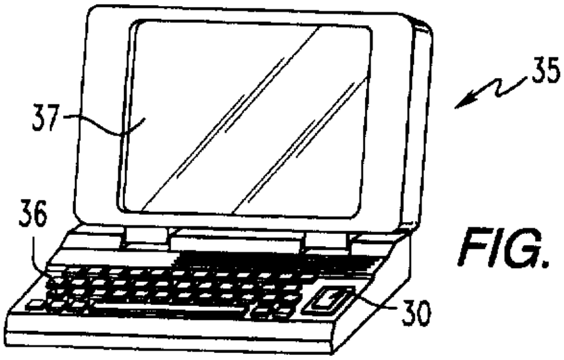

FIG. 1

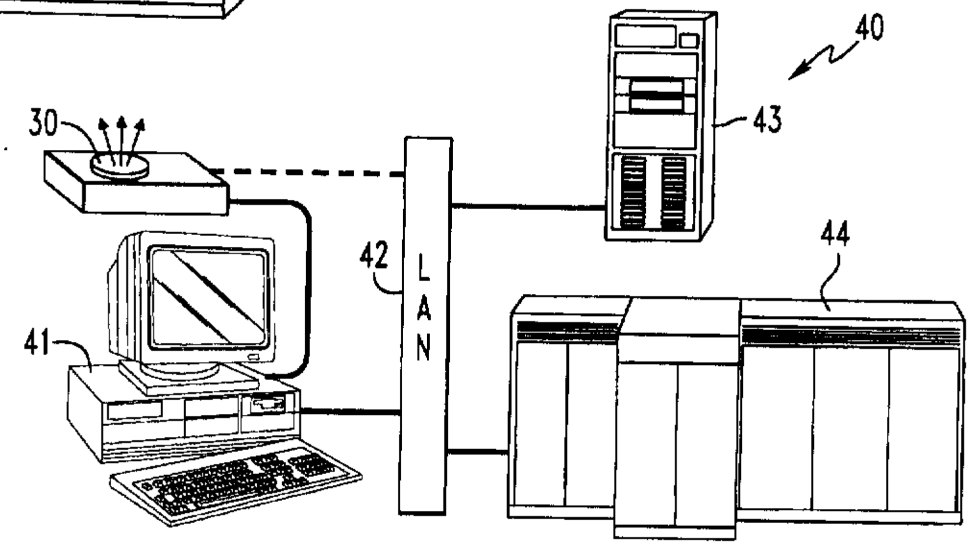

FIG. 2

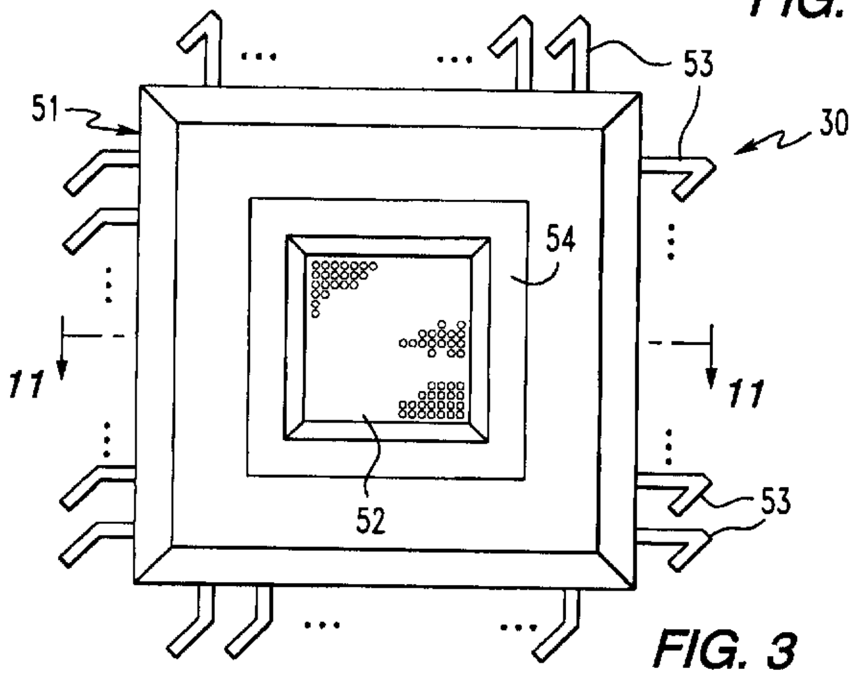

FIG. 3

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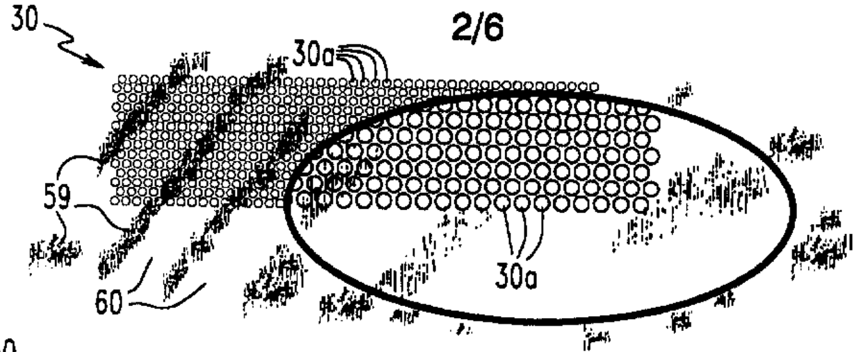

FIG. 4

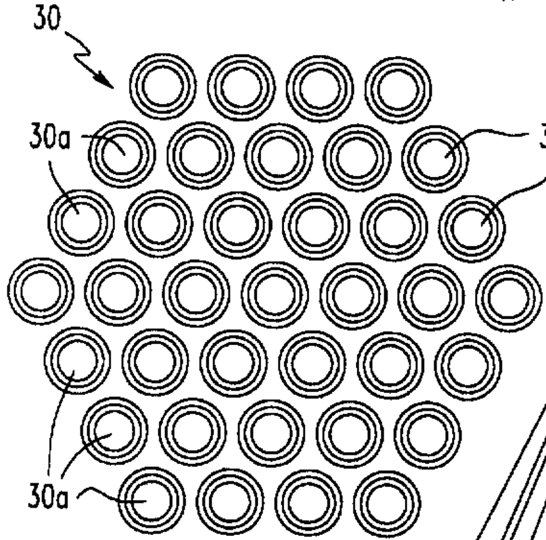

FIG. 5

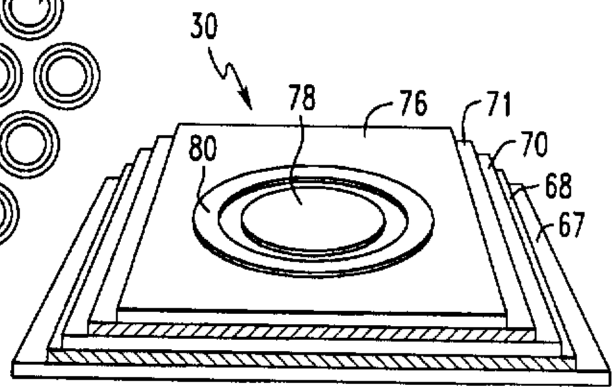

FIG. 6

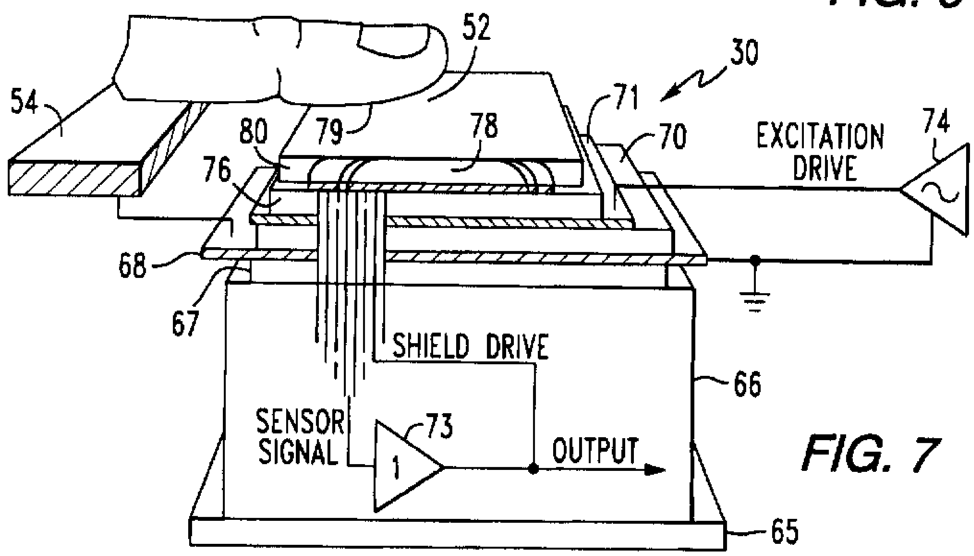

FIG. 7

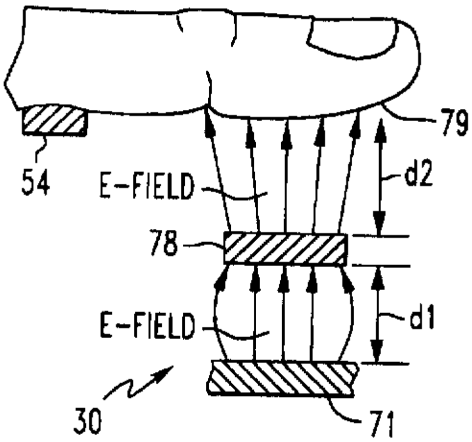

FIG. 8

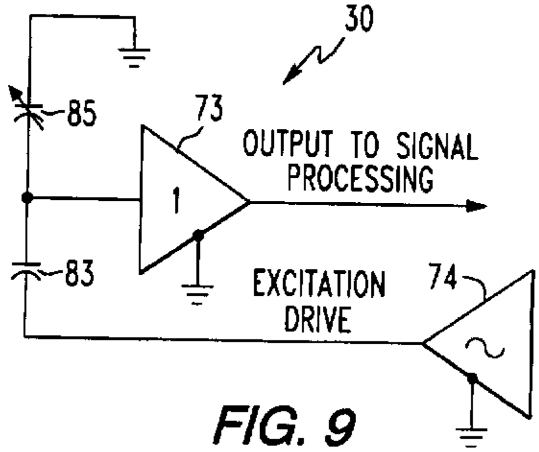

FIG. 9

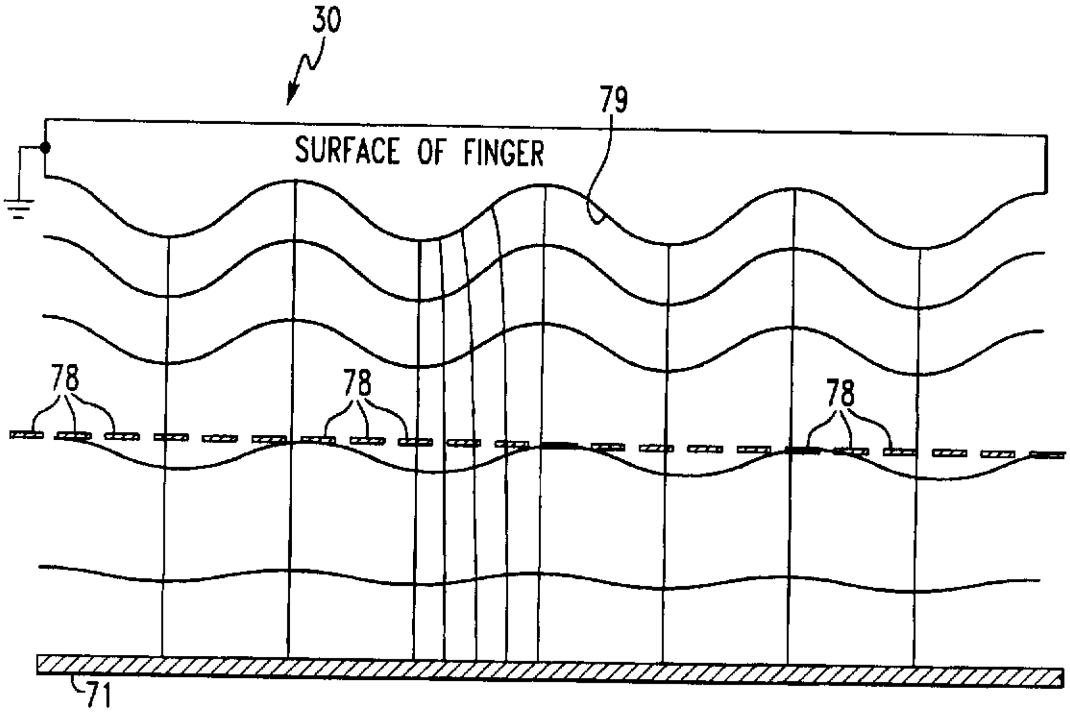

FIG. 10

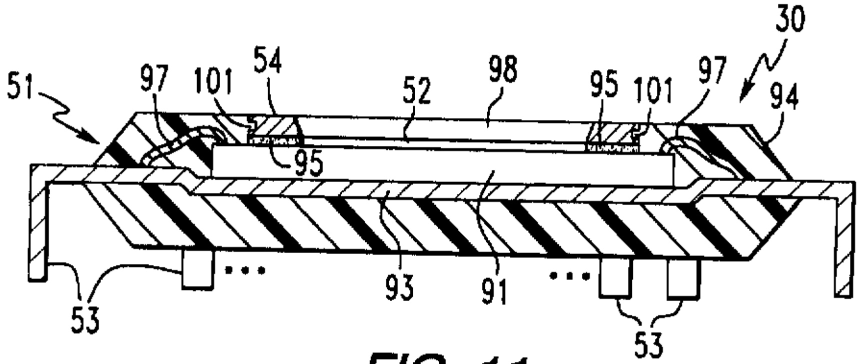

FIG. 11

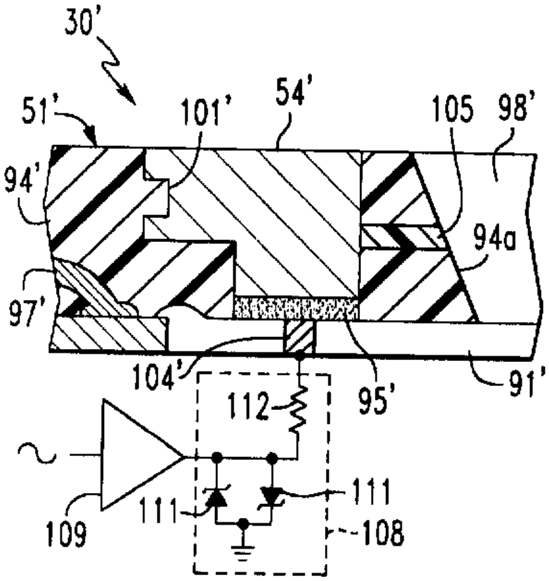

FIG. 12

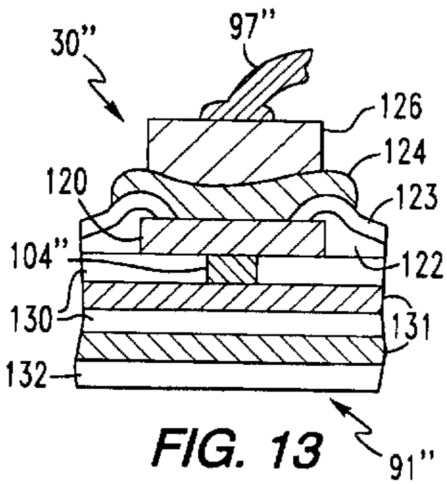

FIG. 13

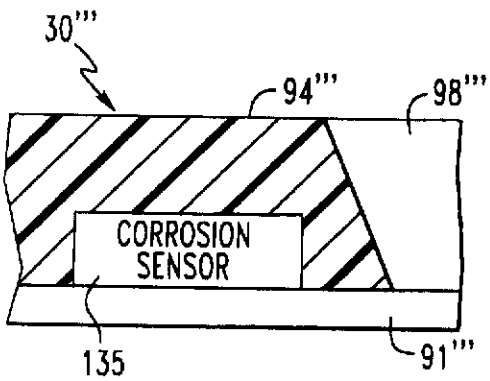

FIG. 14

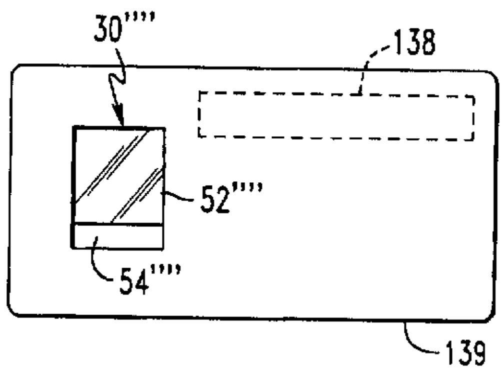

FIG. 15

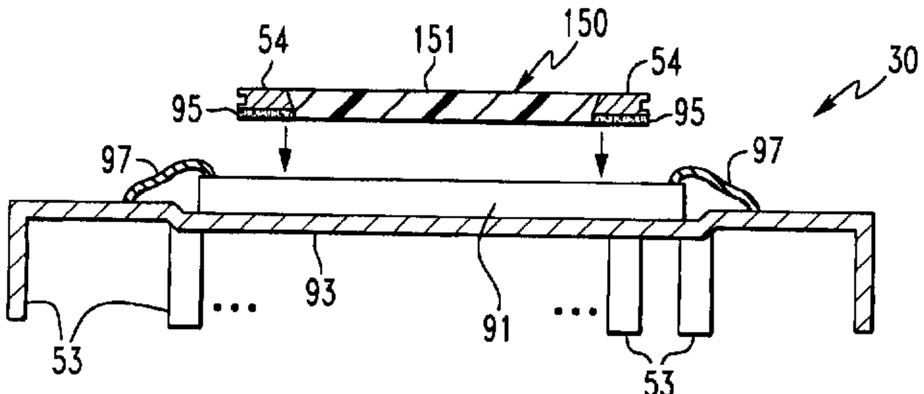

FIG. 16

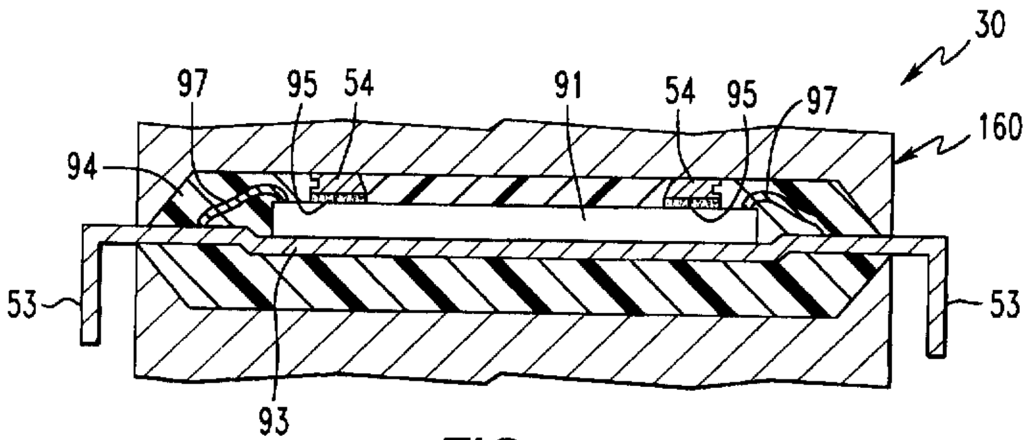

FIG. 17

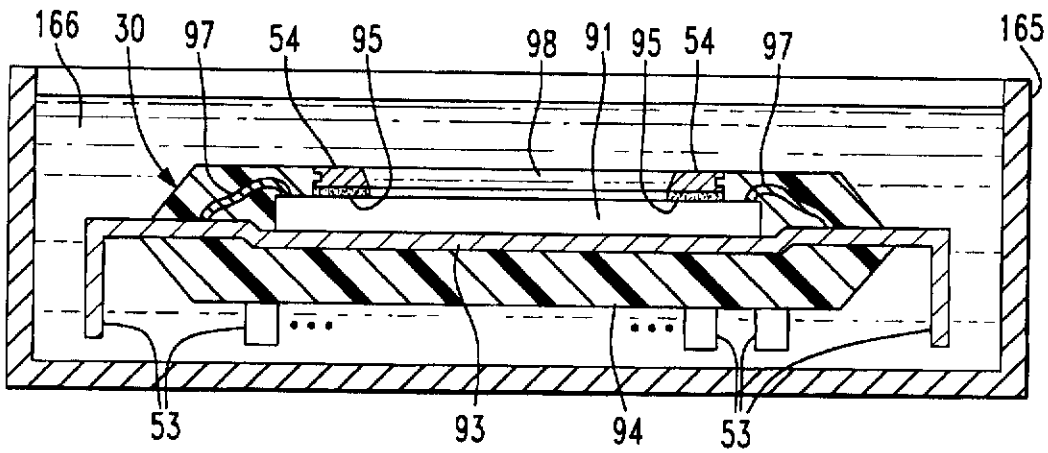

FIG. 18

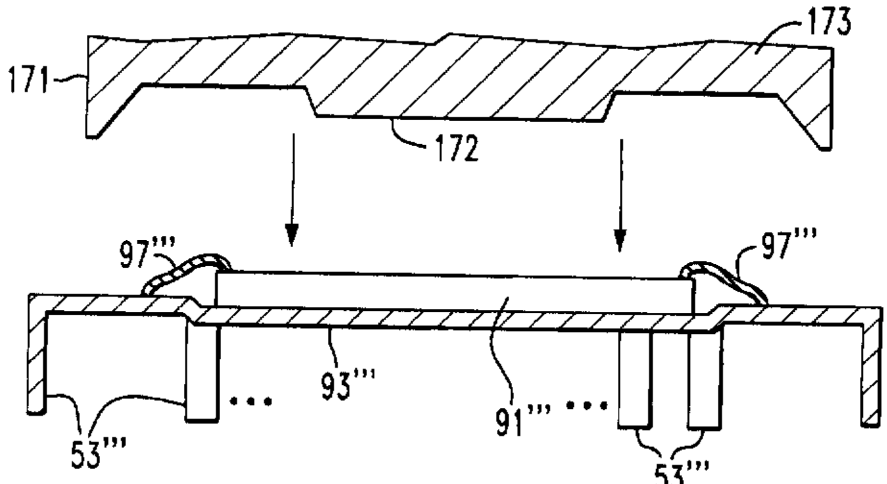

FIG. 19

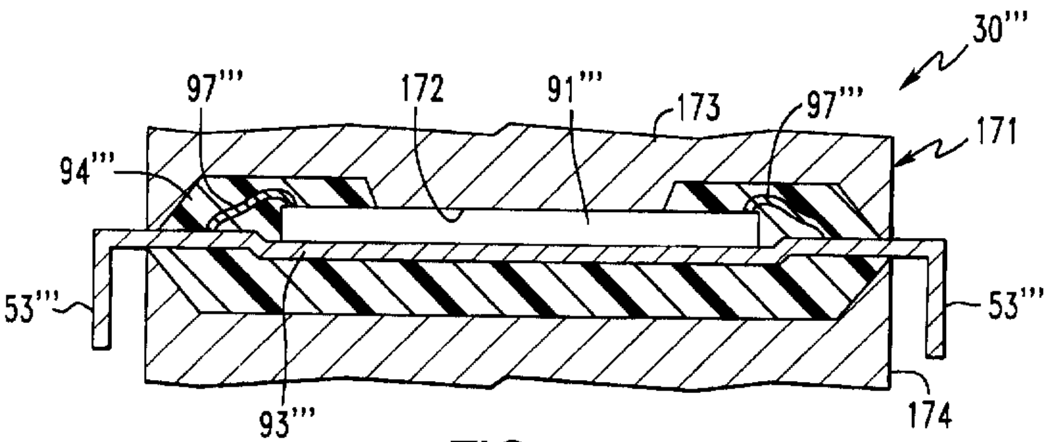

FIG. 20

INTEGRATED CIRCUIT DEVICE HAVING AN OPENING EXPOSING THE INTEGRATED CIRCUIT DIE AND RELATED METHODS

RELATED APPLICATION

This application is a continuation-in-part application of U.S. patent application Ser. No. 08/592,472 filed Jan. 26, 1996.

FIELD OF THE INVENTION

The present invention relates to the field of semiconductors, and, more particularly, to an integrated circuit device and package therefor.

BACKGROUND OF THE INVENTION

Several applications may require that the outermost surface of an integrated circuit die be exposed to the environment, such as to be accessible for direct contact with a person or part of a person. For example, certain medical applications position a bare integrated circuit into the blood stream, such as to measure blood chemistry. Fortunately, in such an application the circuit's operational life is limited, and the circuit is used only once before being discarded. Accordingly, long term reliability is not typically a significant issue.

In contrast, a fingerprint sensor based upon an integrated circuit array of sensing elements may require direct contact by the finger with the integrated circuit die. Fingerprint sensing and matching is a reliable and widely used technique for personal identification or verification. One common approach to fingerprint identification involves scanning a sample fingerprint or an image thereof and storing the image and/or unique characteristics of the fingerprint image. The characteristics of a sample fingerprint may be compared to information for reference fingerprints already in storage to determine proper identification of a person, such as for verification purposes.

A typical electronic fingerprint sensor is based upon illuminating the finger surface using visible light, infrared light, or ultrasonic radiation. The reflected energy is captured with some form of camera, for example, and the resulting image is framed, digitized and stored as a static digital image. For example, U.S. Pat. No. 4,210,899 to Swonger et al. discloses an optical scanning fingerprint reader cooperating with a central processing station for a secure access application, such as admitting a person to a location or providing access to a computer terminal. U.S. Pat. No. 4,525,859 to Bowles similarly discloses a video camera for capturing a fingerprint image and uses the minutiae of the fingerprints, that is, the branches and endings of the fingerprint ridges, to determine a match with a database of reference fingerprints.

Unfortunately, optical sensing may be affected by stained fingers or an optical sensor may be deceived by presentation of a photograph or printed image of a fingerprint rather than a true live fingerprint. In addition, optical schemes may require relatively large spacings between the finger contact surface and associated imaging components. Moreover, such sensors typically require precise alignment and complex scanning of optical beams. Accordingly, optical sensors may thus be bulky and be susceptible to shock, vibration and surface contamination. Accordingly, an optical fingerprint sensor may be unreliable in service in addition to being bulky and relatively expensive due to optics and moving parts.

U.S. Pat. No. 4,353,056 to Tsikos discloses another approach to sensing a live fingerprint. In particular, the patent discloses an array of extremely small capacitors located in a plane parallel to the sensing surface of the device. When a finger touches the sensing surface and deforms the surface, a voltage distribution in a series connection of the capacitors may change. The voltages on each of the capacitors is determined by multiplexor techniques. Unfortunately, the resilient materials required for the sensor may suffer from long term reliability problems. In addition, multiplexing techniques for driving and scanning each of the individual capacitors may be relatively slow and cumbersome. Moreover, noise and stray capacitances may adversely affect the plurality of relatively small and closely spaced capacitors.

U.S. Pat. No. 5,325,442 to Knapp discloses a fingerprint sensor including a plurality of sensing electrodes. Active addressing of the sensing electrodes is made possible by the provision of a switching device associated with each sensing electrode. A capacitor is effectively formed by each sensing electrode in combination with the respective overlying portion of the finger surface which, in turn, is at ground potential. The sensor may be fabricated using semiconductor wafer and integrated circuit technology. The dielectric material upon which the finger is placed may be provided by silicon nitride or a polyimide which may be provided as a continuous layer over an array of sensing electrodes. Further conductors may be provided on the surface of the dielectric material remote from the sensing electrodes and extending over regions between the sensing electrodes, for example, as lines or in grid form, which conductors are grounded in order to improve the electrical contact to the finger surface.

Unfortunately, driving the array of closely spaced sensing electrodes as disclosed in the Knapp et al. patent may be difficult since adjacent electrodes may affect one another. Another difficulty with such a sensor may be its ability to distinguish ridges and valleys of a fingerprint when the conductivity of the skin and any contaminants may vary widely from person-to-person and even over a single fingerprint. Yet another difficulty with such a sensor, as with many optical sensors, is that different portions of the fingerprint may require relatively complicated post image collection processing to provide for usable signal levels and contrast to thereby permit accurate determination of the ridges and valleys of the fingerprint.

Greater advances in fingerprint sensing and matching for identification and verification are desirable and may prevent unauthorized use of computer workstations, appliances, vehicles, and confidential data. Inexpensive and effective fingerprint identification may also be used at point-of-sale terminals, and ensure further security of credit and debit cards, firearms, and provide a personal electronic signature. Unfortunately, current sensors and their associated circuitry may be too bulky, expensive and unreliable for a great many applications which would otherwise benefit from fingerprint identification and verification technology.

Even though several integrated circuit approaches to fingerprint sensing have been described, there are significant difficulties in packaging such a sensor. As mentioned above, direct physical contact with an integrated circuit die is counter to conventional integrated circuit manufacturing and packaging concepts. Water vapor and other contaminants may enter any interface between the integrated circuit die and the surrounding package thereby potentially significantly reducing reliability. Moreover, even if a reliable package were to be designed, low cost mass production techniques would still be desirable for implementing the

packaging design. Other sensors and integrated circuit devices may also desirably benefit from packaging advances which provide an integrated circuit device including a package which exposes the integrated circuit die, yet which provides environmental protection for other portions of the die, such as the bond pads and bond wires.

SUMMARY OF THE INVENTION

In view of the foregoing background, it is therefore an object of the present invention to provide an integrated circuit device and related methods permitting direct contact of the integrated circuit die by the sensed medium, such as the finger of a user, for example, and while providing a reliable environmental seal for the die.

It is another object of the present invention to provide such an integrated circuit device and related methods which facilitate large scale and relatively low cost manufacturing.

These and other objects, advantages and features of the present invention are provided in one embodiment by a fingerprint sensing device comprising an integrated circuit die, a body of encapsulating material surrounding the integrated circuit die and having an opening therein exposing a fingerprint sensing portion of the die, and an electrically conductive member or frame being mounted to the body of encapsulating material adjacent the opening therein. The electrically conductive member may preferably be positioned so as to define at least a portion of a frame for the opening in the body of encapsulating material. In one embodiment, the electrically conductive member may have a closed geometric shape and define a complete frame for the opening.

The electrically conductive member may be adhesively secured to the integrated circuit die. Accordingly, the electrically conductive member, and adhesive may serve to seal the interface between the body of encapsulating material and the die. The electrically conductive member may define a frame that surrounds a body of removable material during an intermediate stage in manufacturing. More particularly, the body of removable material and its frame may be positioned on the integrated circuit die while plastic is injection molded to encapsulate the assembly. The body of removable material may then be removed thereby forming the opening in the body of encapsulating material and leaving the electrically conductive frame secured to the surrounding body of encapsulating material. In this embodiment, the electrically conductive member defines a frame during manufacturing and facilitates formation of the opening to expose the adjacent portion of the integrated circuit die. The electrically conductive member may also be part of the circuitry of the integrated circuit device.

The integrated circuit device may preferably include interconnection means for electrically connecting the electrically conductive member to the integrated circuit die. For example, the interconnection means may include an electrically conductive adhesive between the electrically conductive member and the integrated circuit die, and at least one conductor filled via in the integrated circuit die.

For a fingerprint sensing embodiment of the invention, the integrated circuit die may comprise an electric field fingerprint sensor. More particularly, the electric field fingerprint sensor may preferably comprise an array of electric field sensing electrodes, a dielectric layer adjacent the electric field sensing electrodes, and drive means for applying an electric field drive signal to the electric field sensing electrodes and adjacent portions of the finger so that the electric field sensing electrodes produce a fingerprint image signal.

Accordingly, the electrically conductive member may serve as an electrode for the fingerprint sensing portion.

Another aspect of the present invention is based upon the user contacting the integrated circuit device, such as to sense a fingerprint. Since the electrically conductive member is contacted by the finger of the user, voltage clamping means is preferably operatively connected to the electrically conductive member for clamping a voltage thereof to remove electrostatic buildup to thereby protect the integrated circuit device from electrostatic discharge damage and/or to protect the user from electrical shock when contacting the integrated circuit device.

The integrated circuit die preferably further comprises a plurality of bond pads. Accordingly, the body of encapsulating material preferably covers the plurality of bond pads. In addition, bond pad sealing means may be provided for protecting the plurality of bond pads from corrosion. Each of the bond pads may comprise a first metal layer, such as comprising aluminum. Accordingly, the bond pad sealing means may comprise a barrier metal layer on the first metal layer. The bond pad sealing means may further comprises a layer of gold on the barrier metal layer. The bond pad sealing means may be used with the electrically conductive member providing a frame and sealing the interface with the die. Alternatively, in some embodiments the bond pad sealing means may be used without the electrically conductive member or frame member.

The body of encapsulating material preferably comprises injection molded plastic. Locking means is preferably defined at an interface between the electrically conductive member or frame member and the body of encapsulating material for forming a mechanical lock therebetween. Corrosion sensing means may be associated with the integrated circuit die to provide a further backup to ensure reliability such as by indicating the integrated circuit's feasible end of life. The integrated circuit device may also comprise a lead frame connected to the integrated circuit die. In addition, the electrically conductive member may comprise a metal, such as gold, for example. The integrated circuit die preferably comprises a robust outermost passivating layer of at least one of a nitride, carbide, or diamond, for example.

Another aspect of the invention is that the integrated circuit die may comprise a relatively rigid substrate, such as a silicon substrate, and a plurality of metal layers on the substrate. The metal layers are preferably relatively thin and relatively rigid to provide additional strength to the integrated circuit die, since the die is typically touched by the user. Preferably each of the plurality of metal layers comprises a refractory metal, such as tungsten, molybdenum, or titanium. Considered another way, according to this aspect of the invention each of the plurality of metal layers is preferably devoid of relatively soft aluminum.

A method aspect according to the present invention is for making an integrated circuit device. The method preferably comprises the steps of: providing an integrated circuit die; positioning a body of removable material on the integrated circuit die; forming a body of encapsulating material around the integrated circuit die and the body of removable material; and removing the body of removable material to define an opening through the body of encapsulating material to expose a portion of the integrated circuit die. The integrated circuit die may be a sensor, such as a fingerprint sensor, or other integrated circuit device.

The method may further comprise the step of securing a frame member to the body of removable material. The frame member may comprise an electrically conductive material.

In addition, the step of removing the body of removable material preferably includes removing same while the frame member remains in place with the body of encapsulating material. The step of positioning the body of removable material preferably includes the step of adhesively securing the frame member to the integrated circuit die. The step of forming the body of encapsulating material may include injection molding plastic around the body of removable material and the integrated circuit die. In addition, the body of removable material may preferably be a body of material soluble in liquid, and wherein the step of removing preferably includes exposing the body of material to the liquid solvent.

Another method aspect of the invention is for making an integrated circuit device comprising the steps of: providing an integrated circuit die; positioning a mold having a body and a protrusion extending outwardly therefrom on the integrated circuit die so that the protrusion contacts a portion of the integrated circuit die; and positioning encapsulating material within the mold and surrounding the integrated circuit die. The method also preferably includes the step of removing the mold including the protrusion to define an opening through the body of encapsulating material to thereby expose a portion of the integrated circuit die.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of an integrated circuit fingerprint sensor in combination with a notebook computer in accordance with the present invention.

FIG. **2** is a schematic diagram of an integrated circuit fingerprint sensor in combination with a computer workstation and associated information processing computer and local area network (LAN) in accordance with the present invention.

FIG. **3** is a schematic perspective view of an embodiment of an integrated circuit fingerprint sensor in accordance with the invention.

FIG. **4** is a schematic plan view of a portion of the integrated circuit fingerprint sensor and an overlying fingerprint pattern in accordance with the present invention with a portion thereof greatly enlarged for clarity of illustration.

FIG. **5** is a greatly enlarged plan view of a portion of the integrated circuit fingerprint sensor in accordance with the invention with the upper dielectric layer removed therefrom for clarity of illustration.

FIG. **6** is a schematic perspective view of a portion of the integrated circuit fingerprint sensor in accordance with the present invention.

FIG. **7** is a schematic fragmentary view of a portion of the integrated fingerprint sensor in accordance with the present invention.

FIG. **8** is a schematic side view, partially in section, illustrating the electric fields in accordance with the present invention.

FIG. **9** is a schematic circuit diagram of a portion of the integrated fingerprint sensor in accordance with the present invention.

FIG. **10** is an enlarged schematic side view, partially in section, further illustrating the electric fields in accordance with the present invention.

FIG. **11** is a slightly enlarged schematic cross-sectional view taken along lines **11**—**11** of FIG. **3**.

FIG. **12** is a greatly enlarged schematic cross-sectional view of a portion of an alternate embodiment of an integrated circuit device according to the invention.

FIG. **13** is a greatly enlarged schematic cross-sectional view of a contact pad portion in an embodiment of the integrated circuit device according to the invention.

FIG. **14** is a greatly enlarged schematic cross-sectional view of a portion of an alternate embodiment of an integrated circuit device according to the invention.

FIG. **15** is a plan view of an integrated circuit fingerprint sensing device incorporated into a carrying card in accordance with the present invention.

FIGS. **16**–**18** are schematic cross-sectional views of the integrated circuit device during manufacturing in accordance with a method of the present invention.

FIGS. **19** and **20** are schematic cross-sectional views of the integrated circuit device during another manufacturing process in accordance with a method of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout, and prime and multiple prime notation is used in alternate embodiments to indicate similar elements. The scaling of various features, particularly fingers and layers in the drawing figures, have been exaggerated for clarity of explanation.

Referring first to FIGS. **1**–**3**, an integrated circuit fingerprint sensor **30** in accordance with the invention is initially described. The illustrated fingerprint sensor **30** includes a housing or package **51**, a dielectric layer **52** exposed on an upper surface of the package which provides a placement surface for the finger, and a plurality of signal conductors or leads **53**. A conductive strip or electrode **54** around the periphery of the dielectric layer **52** may also provide a contact electrode for the finger as described in greater detail below. The sensor **30** may provide output signals in a range of sophistication levels depending on the level of processing incorporated in the package as also described in greater detail below.

The integrated circuit fingerprint sensor **30** may be used in many different applications as will be readily appreciated by those skilled in the art, such as for personal identification or verification purposes. For example, the sensor **30** may be used to permit access to a computer workstation, such as a notebook computer **35** including a keyboard **36** and associated folding display screen **37** (FIG. **1**). In other words, user access to the information and programs of the notebook computer **35** may only be granted if the desired or previously enrolled fingerprint is first sensed as also described in greater detail herein.

Another application of the fingerprint sensor **30** is illustrated with particular reference to FIG. **2**. The sensor **30** may be used to grant or deny access to a fixed workstation **41** for a computer information system **40**. The system may include a plurality of such workstations **41** linked by a local area network (LAN) **43**, which in turn, is linked to a fingerprint identification server **43**, and an overall central computer **44**. Many other applications for the low cost and reliable electric field sensor **30** in accordance with the invention are con-

templated by the invention and will be readily appreciated by those skilled in the art.

Referring now additionally to FIGS. **4–10**, the fingerprint sensor **30** in accordance with one aspect of the invention is described in greater detail. The fingerprint sensor **30** includes a plurality of individual pixels or sensing elements **30***a* arranged in array pattern as shown perhaps best in FIGS. **4** and **5**. As would be readily understood by those skilled in the art, these sensing elements are relatively small so as to be capable of sensing the ridges **59** and intervening valleys **60** of a typical fingerprint (FIG. **4**). As will also be readily appreciated by those skilled in the art, live fingerprint readings as from the electric field sensor **30** in accordance with the present invention may be more reliable than optical sensing, because the conduction of the skin of a finger in a pattern of ridges and valleys is extremely difficult to simulate with a fingerprint image on a substrate or even with a three-dimensional model of a fingerprint, for example.

The fingerprint sensor **30** includes a substrate **65**, and one or more active semiconductive layers **66** thereon. In the illustrated embodiment a ground plane electrode layer **68** is above the active layer **66** and separated therefrom by an insulating layer **67**. A drive electrode layer **71** is positioned over another dielectric layer **70** and is connected to an excitation drive amplifier **74**. The excitation drive signal may be typically in the range of about 1 Khz to 1 Mhz and is coherently delivered across all of the array. Accordingly, the drive or excitation electronics are thus relatively uncomplicated and the overall cost of the sensor **30** may be reduced, while the reliability is increased.

Another insulating layer **76** is on the drive electrode layer **71**, and an illustratively circularly shaped sensing electrode **78** is on the insulating layer **76**. The sensing electrode **78** may be connected to sensing electronics **73** formed in the active layer **66** as schematically illustrated, and as would be readily appreciated by those skilled in the art.

An annularly shaped shield electrode **80** surrounds the sensing electrode **78** in spaced relation therefrom. As would be readily appreciated by those skilled in the art the sensing electrode **78** and its surrounding shield electrode **80** may have other shapes, such as hexagonal, for example, to facilitate a close packed arrangement or array of pixels or sensing elements **30***a*. The shield electrode **80** is an active shield which is driven by a portion of the output of the amplifier circuit **73** to help focus the electric field energy and, moreover, to thereby reduce the need to drive adjacent electrodes. Accordingly, the sensor **30** permits all of the sensing elements to be driven by a coherent drive signal in sharp contrast to prior art sensors which required that each sensing electrode be individually driven.

As understood with additional reference to FIGS. **8–10**, the excitation electrode **71** generates a first electric field to the sensing electrode **78** and a second electric field between the sensing electrode **78** and the surface of the finger **79**, over the distances d1 and d2, respectively. In other terms, a first capacitor **83** (FIG. **9**) is defined between the excitation electrode **71** and the sensing electrode **78**, and a second capacitor **85** is defined between the finger skin **79** and ground. The capacitance of the second capacitor **85** varies depending on whether the sensing electrode **78** is adjacent a fingerprint ridge or valley. Accordingly, the sensor **30** can be modeled as a capacitive voltage divider. The voltage sensed by the unity gain voltage follower or amplifier **73** will change as the distance d2 changes.

In general, the sensing elements **30***a* operate at very low currents and at very high impedances. For example, the

output signal from each sensing electrode **78** is desirably about 5 to 10 millivolts to reduce the effects of noise and permit further processing of the signals. The approximate diameter of each sensing element **30***a*, as defined by the outer dimensions of the shield electrode **80**, may be about 0.002 to 0.005 inches in diameter. The excitation dielectric layer **76** and surface dielectric layer **52** may desirably have a thickness in the range of about 1 μm. The ground plane electrode **68** shields the active electronic devices from the excitation electrode **71**. A relatively thick dielectric layer **67** will reduce the capacitance between these two structures and thereby reduce the current needed to drive the excitation electrode. The various signal feedthrough conductors for the electrodes **78**, **80** to the active electronic circuitry may be readily formed as would be understood by those skilled in the art. In addition, the illustrated signal polarities may be readily reversed as would also be readily understood by those skilled in the art.

The overall contact or sensing surface for the sensor **30** may desirably be about 0.5 by 0.5 inches —a size which may be readily manufactured and still provide a sufficiently large surface for accurate fingerprint sensing and identification. The sensor **30** in accordance with the invention is also fairly tolerant of dead pixels or sensing elements **30***a*. A typical sensor **30** includes an array of about 256 by 256 pixels or sensor elements, although other array sizes are also contemplated by the present invention. The sensor **30** may also be fabricated at one time using primarily conventional semiconductor manufacturing techniques to thereby significantly reduce the manufacturing costs.

Turning now additionally to FIG. **11** the packaging of the fingerprint sensor **30** is further described. As would be readily understood by those skilled in the art, an integrated circuit fingerprint sensor presents a special packaging difficulty since it has to be touched by the finger being scanned or sensed. It is typically desired to avoid touching of an integrated circuit in conventional integrated circuit fabrication, in part, because of potential contamination. The main contaminants of concern may be sodium and the other alkaline metals. These ionic contaminants have very high mobility in the SiO_2 layers that are typically used to passivate the integrated circuit. The resulting oxide charge may degrade device characteristics especially in MOS technology.

One conventional approach to controlling mobile ionic contamination uses hermetic packaging with a phosphorus-doped passivation layer over the integrated circuit. The phosphorus doping reduces contaminant mobility by trapping mechanisms as would be readily understood by those skilled in the art. Plastic packaging has now become more widespread, and a silicon nitride or silicon carbide passivation layer may be used with the plastic packaging. Silicon nitride or silicon carbide may greatly reduce the permeability to contaminants to permit direct contact between the finger of the user and the integrated circuit. Accordingly, silicon nitride or silicon carbide may preferably be used as an outermost passivation layer of the fingerprint sensor **30** in accordance with an embodiment of the present invention.

An integrated circuit device, such as the fingerprint sensor **30**, also raises several unique packaging requirements including: the package needs to be open to enable finger-to-sensor die contact; the package should be physically strong in order to withstand rough use; the package and die should be able to withstand repeated cleaning with detergent and/or disinfectant solutions, and including scrubbing; the die should be able to withstand contact with a wide variety of organic and inorganic contaminants, and should be able to

withstand abrasion; and finally the package should be relatively inexpensive.

The illustrated package **51** addresses these packaging issues. The package **51** includes an integrated circuit die **91** mounted on a lead frame **93** during injection molding to form the body **94** of encapsulating material of the package. Connections are made by bond wires **97** and the lead frame **93** to the outwardly extending leads **53** as would be readily understood by those skilled in the art. The upper surface of the package **51** includes an integrally molded opening **98** which direct permits contact to the die **91**. More particularly, the opening **98** is defined in the illustrated embodiment by a frame member or electrically conductive member which serves as an electrode **54**. The electrode **54** is illustratively connected to the underlying portion of the die **91** by an electrically conductive adhesive **95** which provides advantages in manufacturing of the sensor **30** as explained in greater detail below.

The inner exposed sides of the electrode **54** may be slightly angled as shown in the illustrated embodiment. As also shown in the illustrated embodiment, the frame member or electrode **54** is mechanically held in position within the body **94** of surrounding encapsulating material by an interlocking fit between a tongue of plastic material and a corresponding groove in the electrode. Of course, those of skill in the art will recognize other arrangements of interlocking means at the interface between the body **94** and the electrode **54**.

As will be readily appreciated by those skilled in the art, the electrode **54** may be advantageously interconnected to circuitry within the integrated circuit die **91**. In particular with reference additionally to FIG. **12**, a conductor filled via **104** may be used to connect to the electrode **54'**. As also shown in FIG. **12**, an alternate mechanical locking arrangement is illustrated at the interface between the body **94'** of encapsulating material and the electrode **54'**. The illustrated electrode **54'** has an L-shaped cross-section and those of skill in the art will readily appreciate that other cross-sectional shapes are possible and are contemplated by the present invention.

In addition, FIG. **12** illustrates an embodiment of the invention wherein the electrode **94'** is set back from the opening **98'**. More particularly, a strut **105** may be used to hold a body of removable material to form the opening during molding as described in greater detail below. In other words, one or more struts **105** may define a space between the frame member or electrode **54'** and the body of removable material during molding. Accordingly, an inner portion of plastic **94*a*** is formed interior of the electrode **54'** during injection molding.

Yet another advantageous feature illustrated in FIG. **12** relates to clamping a voltage at the electrode **54'**. More particularly, an electrostatic voltage on the user's finger, if not properly dissipated, may damage components of the integrated circuit die **91'** as would be readily understood by those skilled in the art. In addition, a voltage imparted to the electrode **54'** from the drive circuitry **109** should desirably not exceed a predetermined level to avoid accidental shocking of the user. Accordingly, the invention advantageously includes the illustrated voltage clamping circuit **108** provided by the illustrated pair of zener diodes **111** and resistor **112**. Those of skill in the art will readily appreciate that other clamping circuits are also contemplated by the present invention.

As would be readily appreciated by those skilled in the art, in certain embodiments of the fingerprint sensor or other

integrated circuit devices a ground electrode may not be necessary, as the body may serve as a large capacitor itself for the fingerprint sensor. However, the illustrated electrode **54'** may still advantageously provide a conductor for contacting the finger to dissipate static discharge in cooperation with the clamping circuit **109**. As discussed elsewhere herein, in yet other embodiments of the invention, the electrode **54** may not be needed in the final integrated circuit device.

Referring now additionally to FIG. **13** another aspect of the invention is explained. Additional bonding pad protection may be provided in certain embodiments of the invention. In the illustrated structure, a bonding pad **120** of aluminum, for example, is formed on an outer surface of the die. A first passivating layer **122** is formed over the upper die surface and covering edge portions of the bond pad **120**. A second and preferably thicker passivating layer **123** is applied over the first passivating layer **122**. A barrier metal layer **124** is formed on the opening in the second layer **123** and contacts the underlying aluminum bond pad **120**. The barrier metal may be an alloy comprising regions of titanium/tungsten; titanium/tungsten nitride; and titanium/tungsten to protect the underlying relatively corrosion susceptible aluminum. A gold layer **126** may be formed over the barrier metal layer **124**, and a bond wire **97"** connected thereto as would be readily appreciated by those skilled in the art. Those of skill in the art will also readily appreciate other similar structures for protecting the susceptible bond pads **120** from corrosion or degradation as when exposed to water or other contaminants.

The outer passivation layer **123** may comprise silicon nitride for the reasons highlighted above. In addition, another protective coating comprising an organic material, such as polyimide or PTFE (Teflon™) may be provided which yields advantages in wear resistance and physical protection. Inorganic coatings, such as silicon carbide or amorphous diamond, may also be used for the outer layer **123** and may greatly enhance wear resistance, especially to abrasive particles. In addition, the material of the outer passivation layer **123** is preferably compatible with standard integrated circuit pattern definition methods in order to enable bond pad etching, for example.

Yet another significant aspect of the invention understood with reference to FIG. **13** is that the integrated circuit die **91"** may include a plurality of metal layers **131** and intervening dielectric layers **130** supported on a relatively rigid silicon substrate **132**. Conventional annealed aluminum is typically relatively soft and is deposited with a relatively large thickness. Accordingly, one aspect of the present invention is that the metal layers **131** may be provided by a refractory metal or alloys thereof which may be relatively thin and which are relatively rigid. For example, the refractory metal may include tungsten, molybdenum, titanium or alloys thereof. Other refractory metals, and other non-refractory metals may also be used as long as they are relatively rigid and may be formed in a relatively thin layer. For example, for CVD tungsten the thickness is preferably more than about 0.1 μm and preferably less than about 1.0 μm. Considered another way, the metal layers are preferably devoid of aluminum. Thus, the integrated circuit die **91"** is more robust to resist damage as may be caused by direct physical contact with a finger of the user, for example.

Those of skill in the art will readily appreciate that the bond pad sealing means disclosed herein and as illustrated in FIG. **13** may be advantageously used in combination with the interface sealing provided by the adhesively secured electrode **54**. Those of skill in the art will also recognize that

the bond pad sealing means may also be used by itself in certain embodiments, such as shown in FIG. **14** wherein no electrode remains adjacent the opening **98**" for either the full extent of the interface or only a part thereof. As also illustrated in FIG. **14**, corrosion sensing means **135** may be provided to enable control logic on the integrated circuit die **91**''' or remote therefrom to detect corrosion, before failure of the bond pads or other portions of the encapsulated device. The corrosion sensing means **135** may be provided by a resistance network which is periodically monitored for a change in value as would be readily understood by those skilled in the art.

Another variation of the fingerprint sensor **30**"" is illustrated in FIG. **15** wherein the integrated circuit die is encapsulated within plastic material defining a card **139** for carrying by the user. The illustrated sensor **30**"" includes only a single electrode portion **54**"" extending along only a portion of the generally rectangular opening. In other embodiments as discussed above, the electrode or frame member may define a closed geometric shape, such as a rectangle. The card **139** may include the illustrated magnetic stripe **138** for carrying data, for example, and which operates in conjunction with the fingerprint sensor **30**"" as would also be readily understood by those skilled in the art. The card **139** may also carry one or more other integrated circuit dies to enable data processing and storage, for example, as would also be understood by those skilled in the art.

The method aspects of the invention are now explained with reference to FIGS. **16–18**. As shown in FIG. **16**, an assembly **150** including the electrode **54**, a body **151** of removable material, and an adhesive layer **95** on the underside of the electrode is aligned over and positioned onto the integrated circuit die **91** which, in turn, has been secured and connected to the lead frame **93**. The thus formed structure is positioned within a conventional integrated circuit package injection mold **160** (FIG. **17**) and the body **94** of encapsulating plastic material is formed as would be readily understood by those skilled in the art. As shown in FIG. **18**, after removal from the injection mold **160**, the structure is positioned in a bath **165** containing a liquid solvent **166**, such as water, for example, so that the body of removable material is dissolved away leaving the opening **98** to the underlying portion of the integrated circuit die **91**. Those of skill in the art will appreciate many materials that may be readily removed to define the opening. In addition, a solvent spray may be used to dissolve the removable material.

Turning now additionally to FIGS. **19** and **20** another method in accordance with the invention for making the integrated circuit device **30**''' (FIG. **14**) is now described. In this embodiment, an upper mold portion **171** includes a body **173** and a protrusion **172** extending downwardly therefrom. The upper mold portion **171** is brought together with the lower mold portion **174**, and plastic encapsulating material **941**''' is injected into thus defined mold cavity as shown in FIG. **20**. As would be readily understood by those skilled in the art, the protrusion **172** may be hollow rather than solid as shown in the illustrated embodiment. The other elements are indicated with a triple prime and are similar to those described above.

Provisions may be made to ensure biasing of the protrusion **172** against the integrated circuit die **91** during injection molding as would also be readily understood by those skilled in the art. The upper and lower mold portions may be parted to free the integrated circuit device **30**'''.

As will be readily appreciated by those skilled in the art, the techniques and structures for defining and sealing an

opening to the surface of an integrated circuit die may be used for many integrated circuit devices. The invention is particularly applicable to a fingerprint sensor **30** wherein direct contact with the finger of the user is performed. The invention may also be used for other sensors, such as gas or liquid sensors, wherein direct exposure of the integrated circuit die to the sensed medium is desirable and wherein other portions of the die are desirably protected from such exposure.

The various embodiments of the fingerprint sensor **30** and its associated processing circuitry may implement any of a number of conventional fingerprint matching algorithms. For example, a suitable fingerprint matching algorithm and indexing approach for quick and efficient searching is described in copending patent application entitled "Methods and Related Apparatus for Fingerprint Indexing and Searching", having Ser. No. 08/589,064, assigned to the assignee of the present invention and the entire disclosure of which is incorporated herein by reference in its entirety.

As would be readily understood by those skilled in the art, fingerprint minutiae, that is, the branches or bifurcations and end points of the fingerprint ridges, are often used to determine a match between a sample print and a reference print database. Such minutiae matching may be readily implemented by the processing circuitry of the present invention as would be readily understood by those skilled in the art. For example, U.S. Pat. Nos. 3,859,633 and 3,893,080 both to Ho et al. are directed to fingerprint identification based upon fingerprint minutiae matching. U.S. Pat. No. 4,151,512 to Riganati et al., for further example, describes a fingerprint classification method using extracted ridge contour data. U.S. Pat. No. 4,185,270 to Fischer II et al. discloses a process for encoding and verification also based upon minutiae. In addition, U.S. Pat. No. 5,040,224 to Hara discloses an approach to preprocessing fingerprints to correctly determine a position of the core of each fingerprint image for later matching by minutiae patterns. The entire disclosures of each of these U.S. patents are incorporated herein by reference.

Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

That which is claimed is:

1. A fingerprint sensing device comprising:

an integrated circuit die comprising a first fingerprint sensing portion for direct contact by a finger of a user, and a second surface portion opposite the first fingerprint sensing portion;

an integrally molded body of encapsulating material surrounding said integrated circuit die including the second surface portion thereof, said body of encapsulating material having an opening therein exposing the first fingerprint sensing portion of said integrated circuit die to adjacent a periphery of the first fingerprint sensing portion to permit direct contact by the finger of the user with the first fingerprint sensing portion; and

an electrically conductive member being mounted to said body of encapsulating material adjacent the opening therein and adjacent the first fingerprint sensing portion so that the finger of the user directly contacts the electrically conductive member as the finger is positioned onto the first fingerprint sensing portion.

2. A fingerprint sensing device according to claim 1 wherein said electrically conductive member is positioned so as to define at least a portion of a frame for the opening in said body of encapsulating material.

3. A fingerprint sensing device according to claim 1 wherein said electrically conductive member has a closed geometric shape.

4. A fingerprint sensing device according to claim 1 wherein said electrically conductive member has a generally rectangular shape.

5. A fingerprint sensing device according to claim 1 further comprising interconnection means for electrically connecting said electrically conductive member to said integrated circuit die.

6. A fingerprint sensing device according to claim 5 wherein said interconnection means comprises:

an electrically conductive adhesive between said electrically conductive member and said integrated circuit die;

at least one via in said integrated circuit die; and

electrically conductive material in said at least one via.

7. A fingerprint sensing device according to claim 1 wherein said first fingerprint sensing portion comprises an electric field fingerprint sensor.

8. A fingerprint sensing device according to claim 7 wherein said electric field fingerprint sensor comprises:

an array of electric field sensing electrodes;

a dielectric layer adjacent said electric field sensing electrodes, said dielectric layer for receiving a finger adjacent thereto; and

drive means for applying an electric field drive signal to said electric field sensing electrodes and adjacent portions of the finger so that said electric field sensing electrodes produce a fingerprint image signal.

9. A fingerprint sensing device according to claim 1 further comprising voltage clamping means operatively connected to said electrically conductive member for clamping a voltage thereof.

10. A fingerprint sensing device according to claim 1 further comprising electrostatic discharge means for reducing an electrostatic charge of a user as the finger of the user touches said electrically conductive member.

11. A fingerprint sensing device according to claim 1 wherein said integrated circuit die further comprises a plurality of bond pads, and wherein said body of encapsulating material covers said plurality of bond pads.

12. A fingerprint sensing device according to claim 11 further comprising bond pad sealing means for protecting said plurality of bond pads from corrosion.

13. A fingerprint sensing device according to claim 12 wherein each of said bond pads comprises a first metal layer, and wherein said bond pad sealing means comprises a barrier metal layer on said first metal layer.

14. A fingerprint sensing device according to claim 13 wherein said bond pad sealing means further comprises a layer of gold on said barrier metal layer.

15. A fingerprint sensing device according to claim 1 wherein said integrated circuit die comprises:

a relatively rigid substrate; and

a plurality of metal layers on said substrate and being relatively thin and relatively rigid to provide strength to said integrated circuit die.

16. A fingerprint sensing device according to claim 15 wherein each of said plurality of metal layers comprises a refractory metal.

17. A fingerprint sensing device according to claim 15 wherein each of said plurality of metal layers is devoid of aluminum.

18. A fingerprint sensing device according to claim 1 further comprising a lead frame connected to said integrated circuit die.

19. A fingerprint sensing device according to claim 1 wherein said electrically conductive member comprises metal.

20. A fingerprint sensing device according to claim 1 wherein said integrated circuit die comprises an outermost passivating layer.

21. A fingerprint sensing device according to claim 20 wherein said outermost passivating layer comprises at least one of a nitride, carbide, and diamond.

22. A fingerprint sensing device according to claim 1 further comprising an adhesive layer between said integrated circuit die and said electrically conductive member.

23. A fingerprint sensing device according to claim 1 wherein said body of encapsulating material comprises plastic.

24. A fingerprint sensing device according to claim 1 wherein said body of encapsulating material comprises injection molded plastic.

25. A fingerprint sensing device according to claim 1 further comprising locking means defined at an interface between said electrically conductive member and said body of encapsulating material for forming a mechanical lock therebetween.

26. A fingerprint sensing device according to claim 1 further comprising corrosion sensing means for sensing corrosion of said integrated circuit die.

27. A fingerprint sensing device comprising:

an integrated circuit die comprising a first fingerprint sensing portion for direct contact by a finger of a user, and a second surface portion opposite the first fingerprint sensing portion;

an integrally molded body of encapsulating material surrounding said integrated circuit die including the second surface portion thereof, said body of encapsulating material having an opening therein exposing the first fingerprint sensing portion of said integrated circuit die to adjacent a periphery of the first fingerprint sensing portion to permit direct contact by the finger of the user with the first fingerprint sensing portion; and

an electrically conductive member being mounted to said body of encapsulating material adjacent the opening therein to define at least a portion of a frame for the opening so that the finger of the user directly contacts the electrically conductive member as the finger is positioned onto the first fingerprint sensing portion.

28. A fingerprint sensing device according to claim 27 wherein said electrically conductive member has a closed geometric shape.

29. A fingerprint sensing device according to claim 27 further comprising interconnection means for electrically connecting said electrically conductive member to said integrated circuit die.

30. A fingerprint sensing device according to claim 27 further comprising voltage clamping means operatively connected to said electrically conductive member for clamping a voltage thereof.

31. A fingerprint sensing device according to claim 27 wherein said integrated circuit die further comprises a plurality of bond pads, and further comprising bond pad sealing means for protecting said plurality of bond pads from corrosion.

32. A fingerprint sensing device according to claim 27 wherein said integrated circuit die comprises:

a relatively rigid substrate; and

a plurality of metal layers on said substrate and being relatively thin and relatively rigid to provide strength to said integrated circuit die.

33. A fingerprint sensing device according to claim **27** further comprising an adhesive layer between said integrated circuit die and said electrically conductive member.

34. A fingerprint sensing device according to claim **27** further comprising locking means defined at an interface between said electrically conductive member and body of encapsulating material for forming a mechanical lock therebetween.

35. A fingerprint sensing device comprising:

an integrated circuit die comprising a first fingerprint sensing portion for direct contact by a finger of a user, and a second surface portion opposite the first fingerprint sensing portion;

an integrally molded body of encapsulating material surrounding said integrated circuit die including the second surface portion thereof, said body of encapsulating material having an opening therein exposing the first fingerprint sensing portion of said integrated circuit die to adjacent a periphery of the first fingerprint sensing portion to permit direct contact by the finger of the user with the first fingerprint sensing portion;

an electrically conductive member mounted to said body of encapsulating material and adjacent the first fingerprint sensing portion so that the finger of the user directly contacts the electrically conductive member; and

voltage clamping means operatively connected to said electrically conductive member for clamping a voltage thereof.

36. A fingerprint sensing device according to claim **35** wherein said voltage clamping means comprises electrostatic discharge means for reducing an electrostatic charge of a user upon the user touching said electrically conductive member.

37. A fingerprint sensing device according to claim **35** wherein said electrically conductive member is positioned so as to define at least a portion of a frame for the opening in said body of encapsulating material.

38. A fingerprint sensing device according to claim **35** wherein said electrically conductive member has a closed geometric shape.

39. A fingerprint sensing device according to claim **35** further comprising an adhesive layer between said integrated circuit die and said electrically conductive member.

* * * * *

EXHIBIT B

US006667439B2

(12) **United States Patent**
Salatino et al.

(10) **Patent No.: US 6,667,439 B2**
(45) **Date of Patent: Dec. 23, 2003**

(54) **INTEGRATED CIRCUIT PACKAGE INCLUDING OPENING EXPOSING PORTION OF AN IC**

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(73) Assignees: **Authentec, Inc.**, Melbourne, FL (US); **Hestia Technologies, Inc.**, Santa Clara, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 30 days.

(21) Appl. No.: **09/931,378**

(22) Filed: **Aug. 16, 2001**

(65) **Prior Publication Data**

US 2002/0088632 A1 Jul. 11, 2002

Related U.S. Application Data

(60) Provisional application No. 60/225,972, filed on Aug. 17, 2000.

(51) **Int. Cl.**[7] **H01L 23/00**

(52) **U.S. Cl.** **174/52.1**; 361/728; 361/752; 257/690; 257/787

(58) **Field of Search** 174/52.1, 52.2, 174/52.3; 361/728, 736, 748, 752; 257/678, 690, 691, 701, 777, 778, 787

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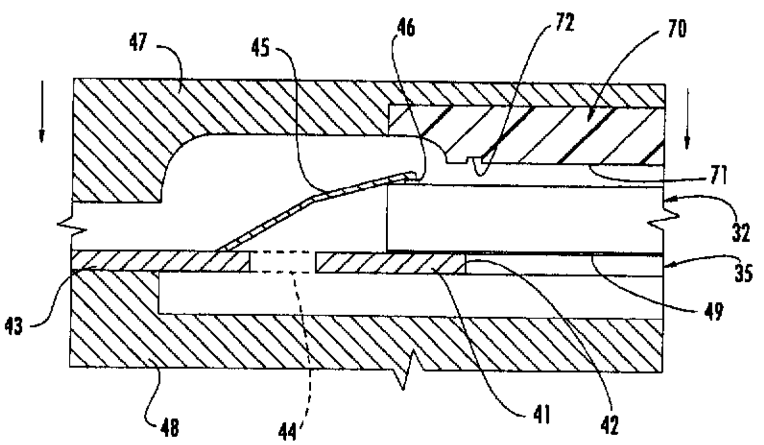
Primary Examiner—Dean A. Reichard
Assistant Examiner—W. David Walkenhorst
(74) *Attorney, Agent, or Firm*—Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A.

(57) **ABSTRACT**

An IC package preferably includes an IC and encapsulating material surrounding the IC, with the encapsulating material having an opening therein to define an exposed portion of the IC. Vestigial portions of encapsulating material may be left on the exposed portion of the IC and spaced inwardly from a periphery of the opening based upon molding using a mold protrusion which includes a bleed-through retention channel positioned inwardly from peripheral edges. The channel collects and retains any bleed-through of the encapsulating material. The IC package may further include a leadframe carrying the IC. The leadframe may include a die pad, finger portions, and a plurality of die pad support bars. The die pad may be downset below a level of the finger portions. Each of the die pad support bars may be resiliently deformed to accommodate the downset of the die pad. Low stress encapsulating material and adhesive may also be included in the IC package.

58 Claims, 5 Drawing Sheets



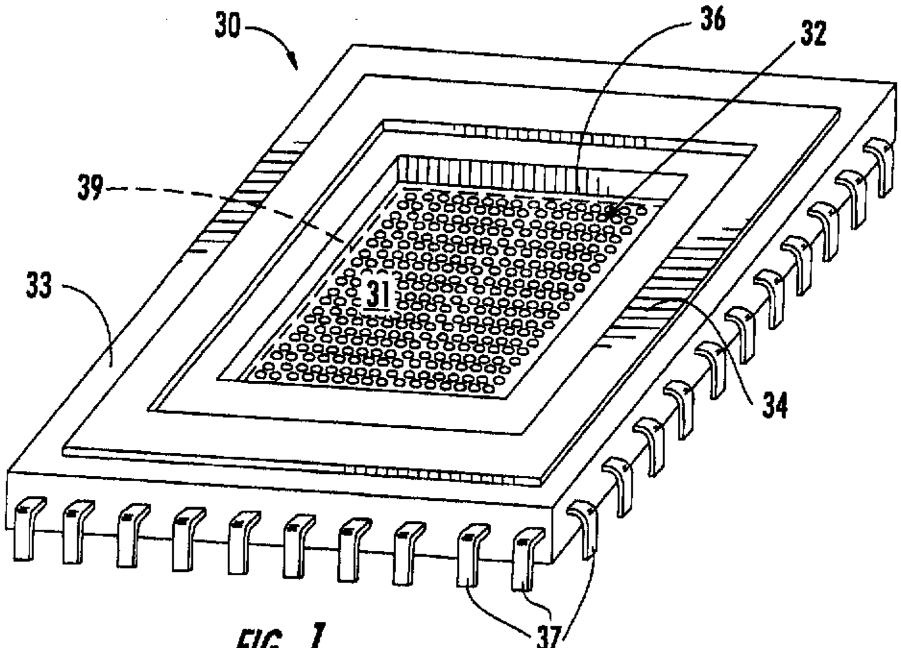


FIG. 1.

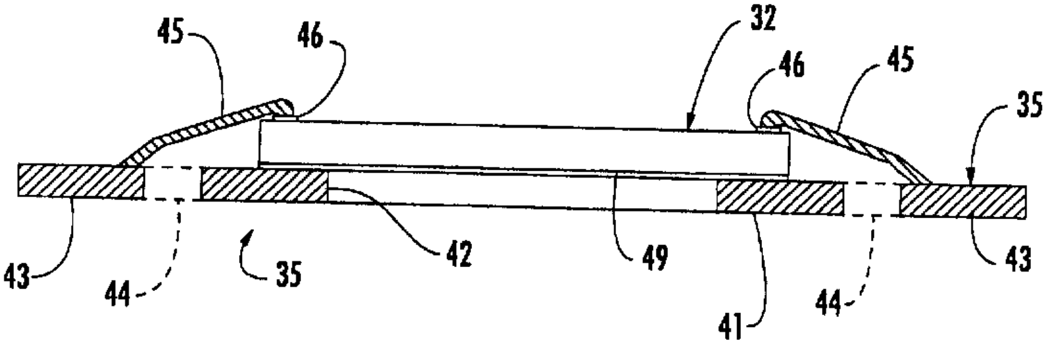


FIG. 2.

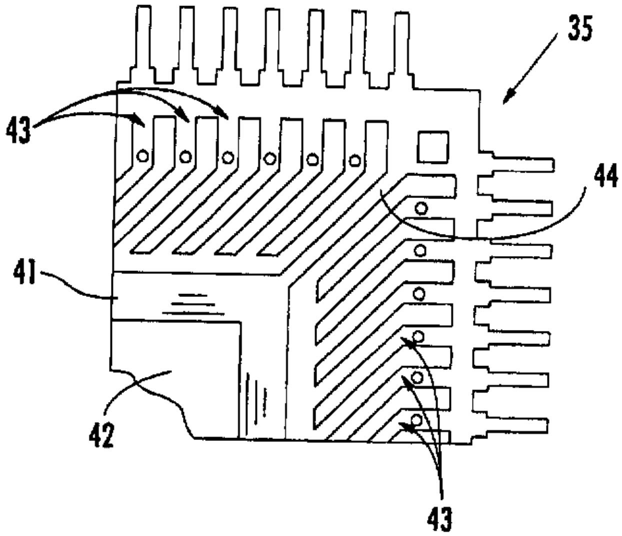


FIG. 3.

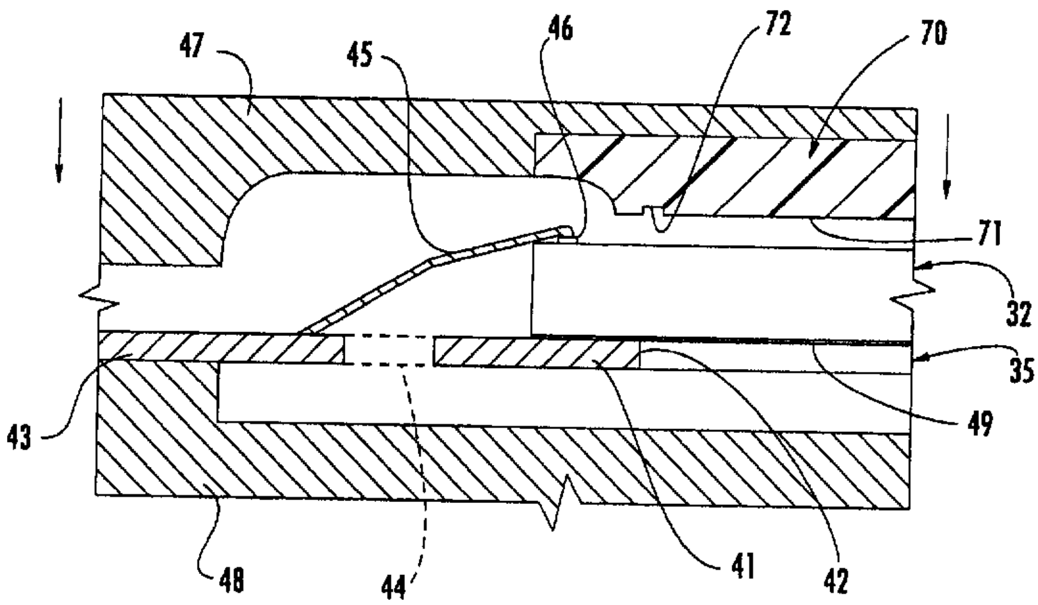
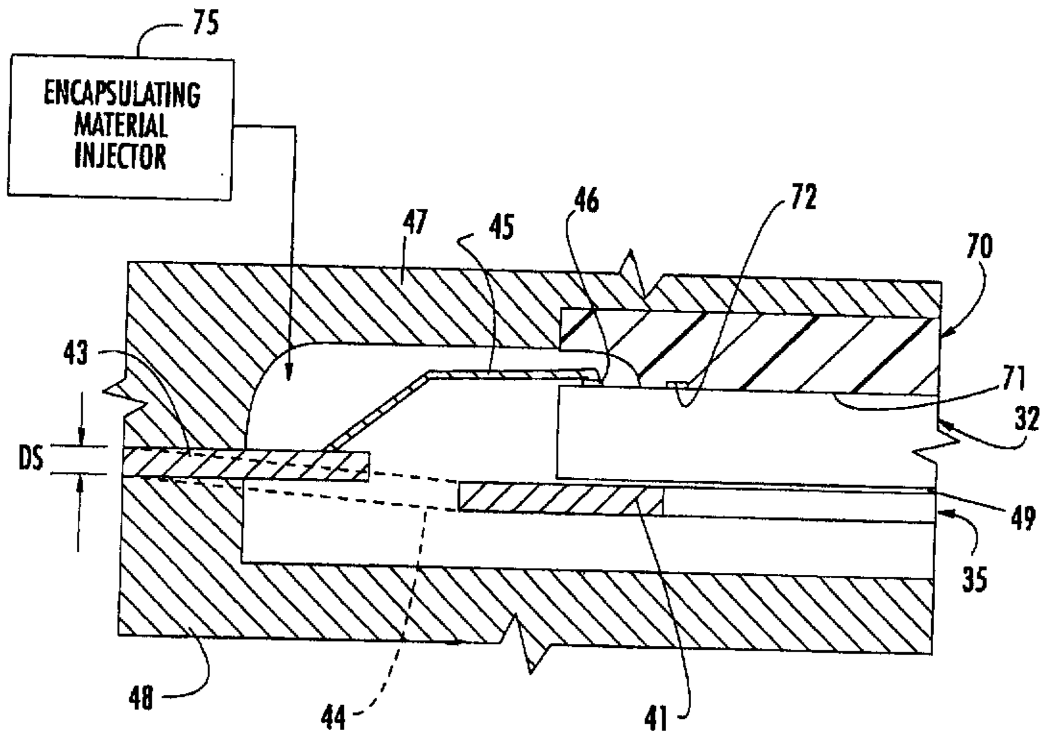
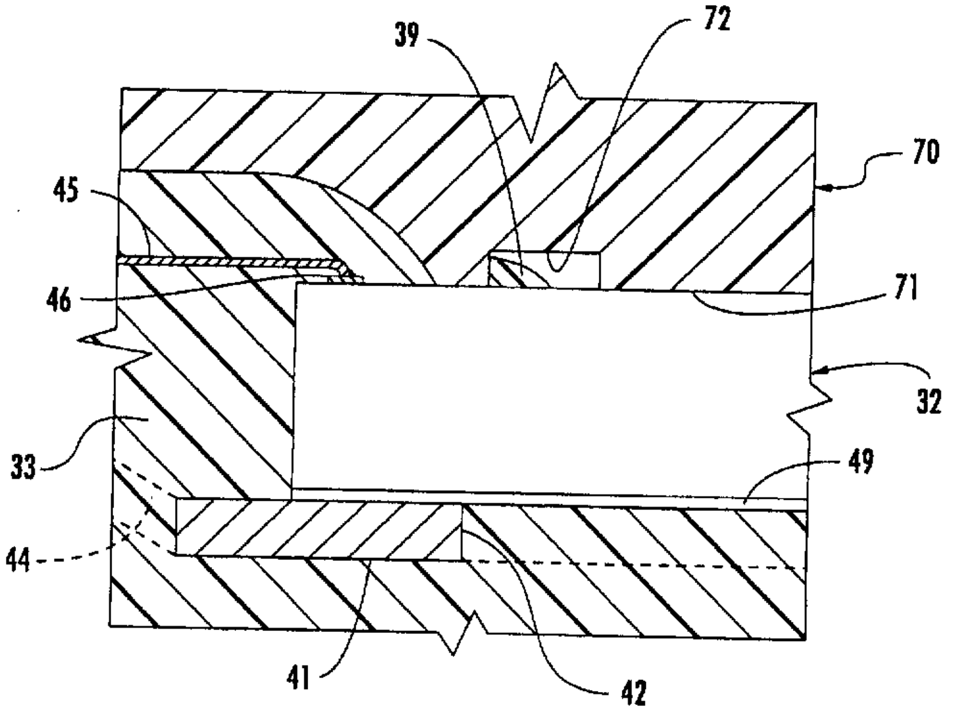


FIG. 4.



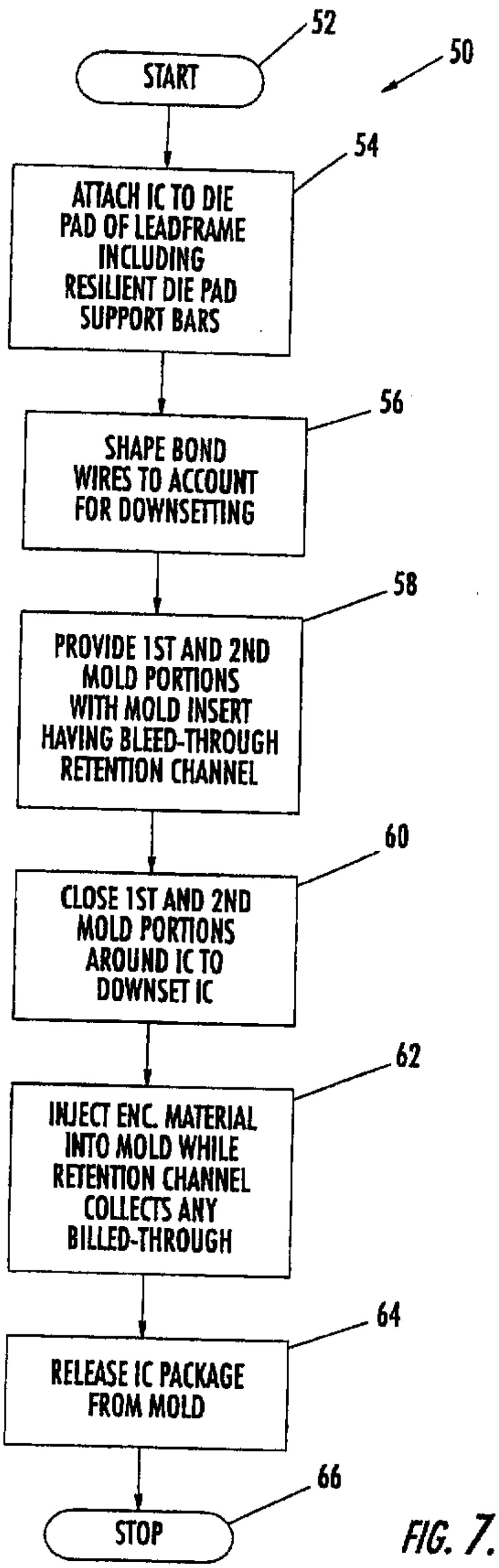
75
ENCAPSULATING MATERIAL INJECTOR
47
45
46
72
70
43
71
32
DS
49
35
48
44
41

FIG. 5.



39
72
70
45
71
46
32
33
49
44
41
42

FIG. 6.



50
52
START
54
ATTACH IC TO DIE PAD OF LEADFRAME INCLUDING RESILIENT DIE PAD SUPPORT BARS
56
SHAPE BOND WIRES TO ACCOUNT FOR DOWNSETTING
58
PROVIDE 1ST AND 2ND MOLD PORTIONS WITH MOLD INSERT HAVING BLEED-THROUGH RETENTION CHANNEL
60
CLOSE 1ST AND 2ND MOLD PORTIONS AROUND IC TO DOWNSET IC
62
INJECT ENC. MATERIAL INTO MOLD WHILE RETENTION CHANNEL COLLECTS ANY BILLED-THROUGH
64
RELEASE IC PACKAGE FROM MOLD
66
STOP

FIG. 7.

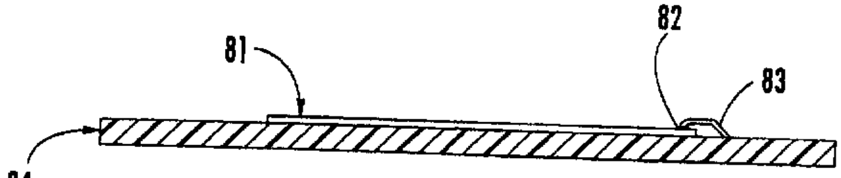


FIG. 8.

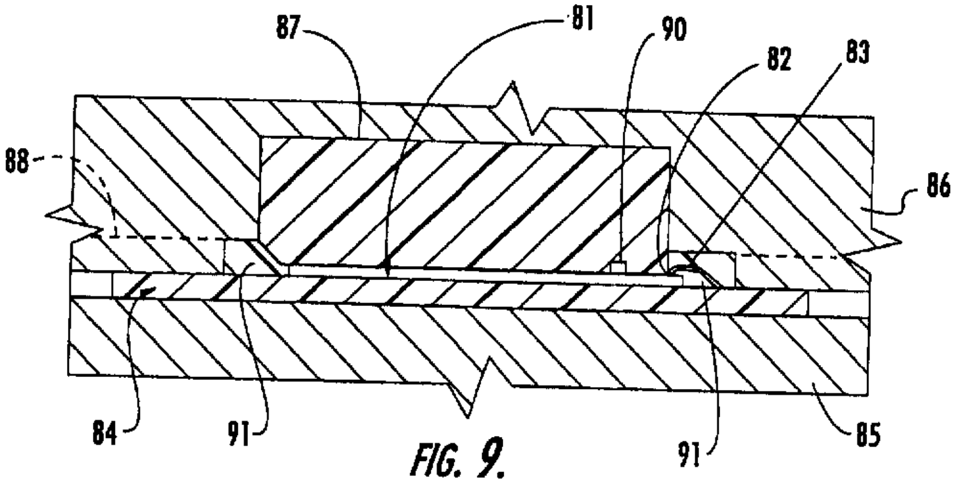


FIG. 9.

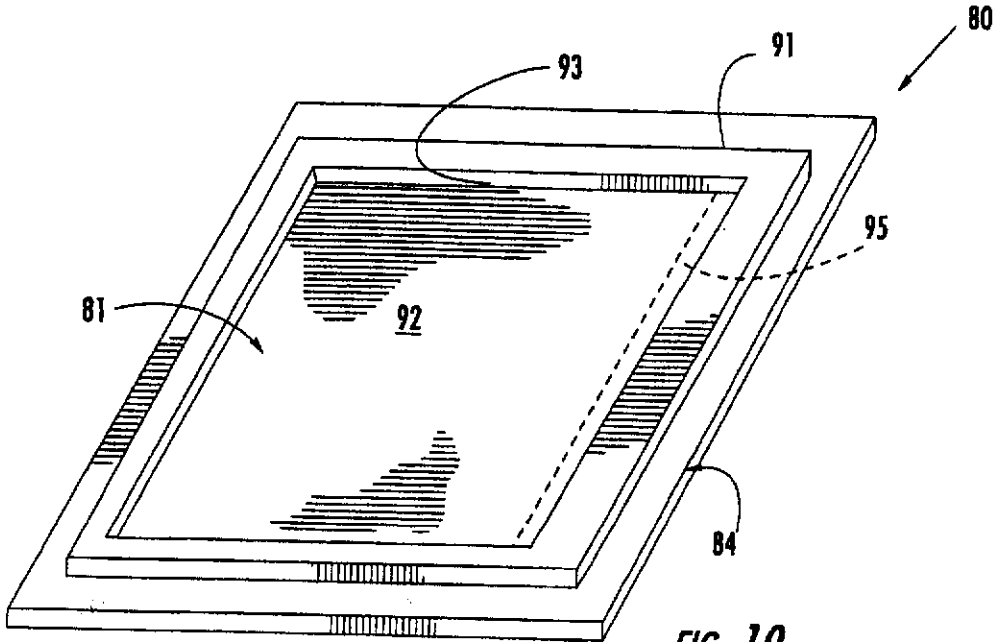


FIG. 10.

INTEGRATED CIRCUIT PACKAGE INCLUDING OPENING EXPOSING PORTION OF AN IC

RELATED APPLICATION

This application is based upon U.S. provisional application serial No. 60/225,972 filed Aug. 17, 2000, the entire contents of which are incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates to the field of electronics, and, more particularly, to integrated circuit packages.

BACKGROUND OF THE INVENTION

Integrated circuit (IC) devices or packages are used in a wide variety of electronic applications including computers, cellular telephones, entertainment systems, etc. A typical IC package includes a chip of semiconductor material, or IC, in which active electronic devices are formed. Surrounding the IC is an encapsulating material, such as typically formed of a thermosetting or thermoplastic resin compound. To protect the IC from damage or contamination, the encapsulating material typically totally surrounds the IC.

The IC itself may be carried by a leadframe. The leadframe includes a die pad which carries the IC, finger portions which provide the electrical pins extending outwardly from the encapsulating material, and die pad support bars which extend from the die pad to the finger portions. Contact or bond pads on the surface of the IC are typically electrically connected to respective finger portions by bond wires which are surrounded by encapsulating material.

IC packaging has typically been concerned with protection and interconnects. Low cost, high volume manufacturing techniques are well established for conventional IC packaging. However, with the advent of various types of sensor, receiving, and/or transmitting circuits based on IC's, the need has arisen to expose some or most of the surface of the IC to the ambient environment. An example of such an IC device is an electric field fingerprint sensor, such as of the type described in U.S. Pat. No. 5,963,679 to Setlak and U.S. Pat. No. 5,862,248 to Salatino et al. Such sensors are available commercially from the assignee of these patents and the present invention, AuthenTec, Inc. of Melbourne, Fla.

The Salatino et al. patent, for example, discloses several approaches for molding the opening in the encapsulating material to expose the fingerprint sensing matrix. One approach uses a frame which holds a body of removable material in its interior and which is positioned on the IC before molding. After molding the body may be removed thereby producing the opening through the encapsulating material. In another embodiment, an upper mold includes a downward protruding portion which directly contacts the IC to exclude the encapsulating material from the surface of the IC during injection molding to thereby form the opening exposing the IC.

Somewhat similar, a number of other patents disclose forming an opening in the encapsulating material from beneath the IC. Accordingly, cooling media may be circulated in the opening, such as disclosed in U.S. Pat. No. 5,687,474 to Hamzehdoost et al. Similarly, U.S. Pat. No. 5,570,272 to Variot provides a heatsink body in the opening beneath the IC. A pressure sensor is disclosed in U.S. Pat. No. 5,424,249 to Ishibashi wherein the encapsulating material is first completely formed then an opening is cut therethrough to an underlying sensing diaphragm.

Methods for packaging IC's with an opening therein have generally been cumbersome and expensive, such as requiring specialized pre-made packaging and flexible or rigid printed circuit boards. These approaches are not well-suited to reliable, high volume, low cost manufacturing. Indeed, despite continuing significant developments, such as those described in the above noted Salatino et al. patent, a number of challenges are still presented for an IC package that exposes a portion of the IC. For example, it may be difficult to keep encapsulating material from bleeding under a mold protrusion that contacts the IC to form the opening. Preventing crush damage to the IC from foreign particles pressed between the mold and the IC also remains a challenge. Variations in the thicknesses of the IC's, adhesive layers, leadframes, etc. as well as accommodating IC skew also remains an area of concern.

SUMMARY OF THE INVENTION

In view of the foregoing background, it is therefore an object of the invention to provide an integrated circuit package comprising an IC and encapsulating material surrounding the IC, but leaving an exposed portion, and wherein the IC package is readily manufactured.

This and other objects, features, and advantages in accordance with the present invention are provided by an integrated circuit package comprising an IC and encapsulating material surrounding the IC, with the encapsulating material having an opening therein to define an exposed portion of the IC. In one class of embodiments, in view of the manufacturing approach, vestigial portions of encapsulating material are left on the exposed portion of the IC and spaced inwardly from a periphery of the opening in the encapsulating material. This is a result of a manufacturing process using a mold protrusion to form the opening. The mold protrusion may include a bleed-through retention channel positioned inwardly from the peripheral edges of an IC-contact surface. The bleed-through retention channel collects and retains any bleed-through of the encapsulating material and prevents its spread further inwardly onto the exposed surface of the IC.

The opening in the encapsulating material may be generally rectangular. Accordingly, the vestigial portions of encapsulating material may be arranged along at least one side of an imaginary rectangle spaced inwardly from the generally rectangular opening in the encapsulating material.

In some embodiments, the IC package may further include a leadframe carrying the IC. More particularly, the leadframe may comprise a die pad, finger portions, and a plurality of die pad support bars extending between the die pad and the finger portions at the corners. The die pad may be downset below a level of the finger portions. In addition, each of the die pad support bars may be resilient deformed to accommodate the downset of the die pad.

The package may further include bond wires extending between the IC and the finger portions. These bond wires may have a desired clearance from adjacent portions of the IC and an upper surface of the encapsulating material when the die pad is downset. In other words, shaping of the bond wires is performed to account for the downset imparted during manufacturing.

To reduce stress during cooling, the die pad may have an opening therein. Further, a low stress, low modulus adhesive may be used to secure the IC to the die pad. The encapsulating material may also be a low stress encapsulating material.

In other embodiments, the IC package may include a substrate on a back surface of the IC opposite the exposed

portion. This substrate may cover the back surface so that the encapsulating material does not extend onto the back surface. In slightly different terms, the substrate, such as a printed circuit board, provides protection for the back surface of the IC and becomes part of the package.

The IC may include upper surface portions with active devices formed therein. The exposed portion of the IC may comprise these upper surface portions. In some advantageous embodiments, the active devices may define a sensor, such as an electric field fingerprint sensor, for example. Other devices may be similarly packaged.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of an exemplary fingerprint sensor IC package in accordance with the present invention.

FIG. **2** is a schematic cross-sectional view of the IC package as shown in FIG. **1** during manufacture.

FIG. **3** is an enlarged plan view of a portion of the leadframe as shown in FIG. **2**.

FIGS. **4** and **5** are schematic partial side cross-sectional views during manufacture of the IC package as shown in FIG. **1**.

FIG. **6** is a greatly enlarged schematic partial side cross-sectional view of the IC package during manufacture thereof after encapsulating material has been injected into the mold.

FIG. **7** is a flowchart of the method for manufacturing the IC package as shown in FIG. **1**.

FIGS. **8** and **9** are schematic cross-sectional views of another embodiment of an IC package during manufacturing thereof.

FIG. **10** is a perspective view of the IC package as shown in FIGS. **8** and **9** upon completion.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

For clarity of explanation, the present invention is explained with reference to manufacturing methods for making an IC package **30** in the illustrated form of an electric field fingerprint sensor IC package as shown in FIG. **1**. The electric field fingerprint sensor IC package **30** may of the type using an electric field to sense the ridges and valleys of a fingerprint as offered by AuthenTec, Inc. of Melbourne, Fla. under the designation FingerLoc™ AF-S2™.

The IC package **30** illustratively corresponds to a JEDEC-standard 68-pin plastic leaded chip carrier (PLCC) format, although other sizes, standards, and configurations are possible. The IC package **30** may be about 24 mm square, and have a height or thickness of about 3.5 mm, for example. Another exemplary package may be a **144** lead LQFP about 1.6 mm thick.

Further details on the operation of the electric field fingerprint sensor may be found in U.S. Pat. Nos. 5,963,679 and 5,862,248 mentioned above, and, the entire disclosures of which are incorporated herein by reference. Of course, other sensors and other devices are also contemplated by the present invention.

The IC package **30** illustratively includes an IC chip or die **32** illustratively including an IC sensor matrix **31** which is exposed through an opening **36** in the upper portion of the encapsulating material **33**. Vestigial portions of encapsulating material may remain on the exposed portion of the IC **32**, outside the area of the sensor matrix **31**. These vestigial portions **39** are schematically indicated in FIG. **1** by the dashed line rectangle and these vestigial portions are described in greater detail below.

The IC package **30** also includes a leadframe on which the IC **32** is mounted as will be described in greater detail below. The leadframe includes a plurality of finger portions which become the visible leads or pins **37** which also extend outwardly from the sides of the encapsulating material **33** as will be appreciated by those of skill in the art. An annular drive ring **34** is provided on the upper surface of the encapsulating material **33** adjacent the opening **36** exposing the sensing matrix **31**. This drive ring **34** is specific to the illustrated electric field fingerprint sensor and is not needed in all such embodiments, or in other IC packages.

For ease of explanation, the term "IC" by itself is used primarily herein for simplicity to denote the actual integrated circuit die as will be appreciated by those of skill in the art. Also for ease of explanation, the term "IC package" is used to indicate the IC **32**, surrounding encapsulating material **33**, leadframe **35**, etc. as an entity.

Referring now additionally to the flowchart **50** of FIG. **7**, and the schematic diagrams of FIGS. **2** through **5**, further details of the manufacturing method and IC package **30** produced thereby are now described. From the start (Block **52**), an IC **32** is attached to a die pad **41** of the leadframe **35** at Block **54**. More particularly, as perhaps best understood with reference to FIGS. **2** and **3**, the leadframe **35** includes a die pad **41** and finger portions **43** which are connected together at each corner by a respective resilient die pad support bar **44**. As will be appreciated by those skilled in the art, the finger portions **43** are later processed to form the visible leads **37** extending outwardly from the encapsulating material **33** as shown in FIG. **1**.

The die pad **41** of the leadframe **35** also illustratively has a central opening **42** therein. This opening **24** reduces stress during cooling of the encapsulating material **33** as will be described in greater detail below. A low stress, low modulus adhesive **49** may also be used to adhesively secure the IC **32** to the die pad **41** as will also be described in greater detail below.

At Block **56** the bond wires **45**, which extend between respective finger portions **43** and bond pads **46** of the IC **32**, are shaped to account for later downsetting. As shown best in FIGS. **2** and **4**, the bond wires **45** are initially shaped so as to be angled downwardly at their upper ends. These upper ends will extend generally horizontally upon downsetting as shown best in FIGS. **5** and **6**.

At Block **58** a mold is provided having first and second, or upper and lower mold portions **47**, **48** as shown in FIG. **4**. The first or upper mold portion **47** preferably carries a mold protrusion **70** defining an IC-contact surface **71** with peripheral edges and a bleed-through retention channel **72** positioned inwardly from the peripheral edges.

At Block **60** the upper and lower mold portions **47**, **48** are closed around the IC **32**. As shown in the illustrated embodiment, the IC-contact surface **71** contacts and presses directly upon the upper surface of the IC **32** and causes the IC to be downset a distance DS as shown in FIG. **5**. In other

words, the resilient die pad support bars **44** permit the IC **32** to be contacted and moved downwardly to the position as shown in FIG. **5** so that the die pad **41** is displaced below the finger portions **43**. Accordingly, a close fit is provided between the IC **32** and contact surface **71** to prevent encapsulating material from bleeding extensively beneath the mold protrusion **70** and onto the surface of the IC **32**, and without crushing the IC.

The downsetting also accommodates skew of the IC surface and variations in thickness of the IC **32**, adhesive layer **49**, and/or portions of the leadframe **35** as will be readily appreciated by those skilled in the art. Considered in somewhat different terms, the manufacturing method includes controlling pressure applied by the IC-contact surface **71** to the IC **32** when the first and second mold portions **47**, **48** are closed around the IC. This may be done as shown in the illustrated embodiment by mounting the IC **32** on the leadframe **35** having resilient portions to resiliently accommodate downsetting of the IC as the IC-contact surface **71** contacts the IC. The resilient die pad support bars **44** as shown in the illustrated embodiment, for example, maintain a desired pressure placed on the IC **32** by the contact surface **71** of the mold protrusion **70** when the mold is closed. The die pad support bars **44** are placed in tension by the downsetting to provide a spring-like force or pressure to IC **32** against the contact surface **71** of the mold protrusion **70**. This pressure is controlled to avoid risk of damage while reducing likelihood of bleed-through of the encapsulating material **33** beneath the contact surface **71** as will be appreciated by those skilled in the art. Considered yet in other terms, the die pad **41** is essentially allowed to float during the molding process. The die pad support bars **44** can readily accommodate tolerance variations of several thousandths of an inch and produce high quality IC packages.

The downsetting also aligns the bond wires **45** in a proper position to provide clearance from adjacent portions of the IC **32** as well as to provide clearance from the adjacent upper surface portions of the encapsulating material **33**. Accordingly shorts from contact with the IC **32**, or bond wires **45** being exposed through the encapsulating material **33** are avoided. As shown in the illustrated embodiment of FIG. **5**, the bond wires **45** in the completed position after downsetting may have upper portions which extend generally horizontally away from the IC **32** before turning downward toward the finger portions **43** of the leadframe **35**.

At Block **62** the encapsulating material **33** is injected into the mold from the schematically illustrated injector **75** under controlled pressure. Those of skill in the art will appreciate detailed construction and operation of the encapsulating material injector **33** without further discussion herein.

As can be seen perhaps best in FIG. **6**, a small bead or line of encapsulating material **33** may bleed under the peripheral edges of the mold protrusion **70** and remain as a vestigial portion **39** of the encapsulating material on the exposed surface of the IC **32**. As will be appreciated by those skilled in the art the relative size of the vestigial portions **39** is greatly exaggerated for clarity of illustration. In short, the bleed-through retention channel **72** retains any encapsulating material bleeding beneath the peripheral edges of the IC contact surface **71**.

It has been found that a flat contact surface of a mold protrusion alone is not likely to reliably prevent the encapsulating material **33** from wicking along the interface between the contact surface **71** and the IC **32**. It is also likely that typical mold clamping pressures cannot be exerted on the IC **32** without considerable risk of damage. Because the

clamping pressure is typically lowered, the potential for bleed-through or wicking of the encapsulating material becomes more important. Accordingly, the bleed-through retention channel **72** may be considered as providing a moat to act as a natural break for the bleeding of the encapsulating material **33** during molding.

The mold protrusion **70** may comprise a resilient material, and have a generally rectangular shape having a side dimension of about 5 to 20 mm for an IC package **30** having a side dimension of about 25 mm, for example. The bleed-through retention channel **72** may be spaced inwardly from the peripheral edges a distance of about 0.2 to 0.4 mm, for example. The retention channel **72** may also have a width of about 1 mm, and a height of about 0.15 to 0.25 mm. Those of skill in the art will appreciate that other sizes are also contemplated by the present invention depending on the application and the size of the IC package.

The IC package **30**, that is, the IC **32**, leadframe **35**, and encapsulating material **33** may be released from the mold at Block **64** before stopping at Block **66**. Those of skill in the art will appreciate that other finishing steps, including trimming excess encapsulating material, and separating the finger portions, for example, are also typically performed to produce the finished IC package **30**.

Another aspect of the manufacturing relates to stress relief. Stress relief may be important since the encapsulating material **33** and the IC **32** typically have different coefficients of thermal expansion (CTEs). It is noted that the leadframe **35** may also have a different CTE. Accordingly, the manufacturing method preferably includes relieving stress during cooling of the encapsulating material **33** despite the different CTEs. The IC package **30** will have an unbalance of thermal-mechanical stress because of the opening **36**. This is in contrast to the balanced stress which results in a balanced compressive force experienced by an IC in a typical fully encapsulated IC.

For example, relieving the stress may comprise using a low stress encapsulating material **33**. For example, the encapsulating material **33** may be a mold compound sold under the designation Plaskon SMT-B1-LV by Cookson Semiconductor Packaging Materials of Alpharetta, Ga. Those of skill in the art will appreciate that other similar mold compounds may be used as well. Alternately or additionally, stress relief may be provided by using a leadframe **35**, such as illustrated and described herein, which includes the die pad **41** with the opening **42** therein. The IC **32** may also be mounted on the die pad **41** using a low stress, low modulus adhesive **49**. For example, the die attach adhesive **49** may be an adhesive sold under the designation Ablebond 8340, and manufactured by Ablestick Electronics Materials and Adhesives (National Starch and Chemical Co.) of Rancho Dominguez, Calif. The low stress, low modulus adhesive **49** and/or open die pad **41** tends to decouple the IC **32** from the leadframe **35** which may typically comprise copper.

As described herein, the IC **32** may have an upper surface with active devices formed therein, such as the illustrated fingerprint sensor with the pixel element matrix **31**. Of course, those of skill in the art will appreciate that the techniques described herein could also be used to expose the back or underside of an IC.

The first and second mold portions **47**, **48** may each comprise a rigid material, such as hardened steel, to provide accurate dimensions and to resist abrasion from the encapsulating material **33**. Although the molding process is relatively clean, small particles may be left on the top of the IC

32 or on the contact surface 71 of the mold protrusion 70 as will be readily appreciated by those skilled in the art. In contrast to the mold portions 47, 48, the mold protrusion 70 may comprise a compliant or resilient material so that any contaminants are not forced into the IC 32 causing damage. The material properties of the mold protrusion 70 are desirably such that any small particles will be pressed into the contact surface 71 instead of into the IC 32. However, it is still desired that the mold protrusion 70 retain its shape through the molding process. The mold tooling is also preferably such as to permit removal of the mold protrusion 70 for cleaning and/or replacement if worn or damaged as will also be appreciated by those skilled in the art.

One attribute of the molding process is that the mold will acquire a build-up of encapsulating material and wax material that may produce aesthetic problems in the finished IC package. Accordingly, mold cleaning is typically performed at periodic intervals. A conventional mold cleaning process entails molding a plastic gettering material, such as melamine, that will adhere to any organic material. After a few molding cycles using the gettering material, normal production is continued. The melamine has a high adhesion to organic particles, but low adhesion to hardened steel mold surfaces.

The mold protrusion 70 can be made of any of a number of appropriate materials. If the mold protrusion 70 is formed of an organic polymer, precautions may be needed to clean the mold, as the conventional melamine cleaning process could potentially damage the compliant mold protrusion by sticking to it and pulling it apart. Several approaches may be used to alleviate this potential difficulty. The organic polymer mold protrusion 70 can be temporarily replaced with a corresponding metal insert during melamine cleaning, for example. A metal or non-stick cap or non-stick coating could be provided over the organic polymer mold protrusion 70.

Returning again to FIGS. 1 through 6, it can be appreciated that the IC package 30 produced using the advantageous processes described herein will have certain distinguishing features and characteristics. For example, in one class of embodiments, in view of the manufacturing approach, vestigial portions 39 of encapsulating material 33 are left on the exposed portion 31 of the IC 32 and spaced inwardly from a periphery of the opening 36 in the encapsulating material. Of course, these vestigial portions 39 could be removed in some embodiments if desired, but simpler and less expensive manufacturing is obtained if the vestigial portions do not effect IC operation and are, therefore, allowed to remain on the IC 32.

As described herein, the opening 36 in the encapsulating material 33 may be generally rectangular. For these embodiments the vestigial portions 39 of encapsulating material are arranged along an imaginary rectangle spaced inwardly from the generally rectangular opening in the encapsulating material. It should be noted that the vestigial portions 39 need not necessarily be connected to form a complete rectangle, rather, the vestigial portions may be spaced, but lie along an imaginary rectangle as defined by the bleed-through retention channel 72 of the mold protrusion 70. For example, the vestigial portions may be spaced inwardly a distance of from 0.1 to 3 mm for an IC package having side dimensions of about 25 mm. Of course, the same principles can be readily applied to other polygonal, round, or other closed geometric shapes as will be appreciated by those skilled in the art.

Another characteristic of the IC package 30 resulting from manufacture as described herein is the downset relationship of the die pad 41 relative to the finger portions 43. The die

pad support bars 44 may also be resiliently deformed to accommodate the downset of the die pad 41. In addition, the bond wires 45 will also likely have a desired clearance from adjacent portions of the IC 32 and an upper surface of the encapsulating material 33 when the die pad 41 is downset.

As also described herein, to reduce stress during cooling, the die pad 41 (FIG. 3) may have an opening 42 therein. Further, a low stress, low modulus adhesive 49 may be used to secure the IC to the die pad 41. The encapsulating material 33 may also be a low stress encapsulating material.

The IC 32 may include upper surface portions with active devices formed therein, such as fingerprint sensing circuitry. The exposed portion of the IC may comprise these upper surface portions. In some advantageous embodiments, the active devices may define a sensor, such as an electric field fingerprint sensor, for example. Other devices may be similarly packaged as will be also readily understood by those skilled in the art.

Turning now additionally to FIGS. 8–10, another embodiment of an IC package 80 and its method of manufacture are now described. As shown in FIG. 8, the IC 81 is adhesively secured to a substrate 84, which may be a printed circuit board, for example. For clarity of explanation, the layer of adhesive is not shown, but may be of the type described above, for example. The substrate 84 may be rigid in some embodiments, but can also be flexible in other embodiments. The substrate 84 may be a ball grid array substrate, or be of the type that with further processing will become a ball grid array substrate. Other substrate types are also contemplated by the invention. In other words, in this IC package 80 the leadframe 35 for mounting the IC and described extensively above is replaced with the substrate 84.

In the illustrated embodiment, the bond pads 82 are also along only one side of the IC 81, and, accordingly, the bond wires 83 are also along only one side of the IC 81. Those of skill in the art will recognize that in other embodiments, the bond pads 82 could be along two, three or all four sides in other embodiments.

The IC 81 and substrate 84 are placed between a lower mold portion 85 and an upper mold portion 86 as shown in FIG. 9, and encapsulating material 91 is injected under controlled pressure. A mold protrusion 87 is provided adjacent the upper mold portion 86. The mold protrusion 87 is desirably relatively compliant so as not to crush foreign particles into the IC 81. Further, in this embodiment, since downsetting of a leadframe 35 is not used to accommodate variations in thicknesses, the compliancy of the mold protrusion 87 accommodates any variations, such as in the thickness of the substrate 84, adhesive layer and/or IC 81. In one example, the mold protrusion 87 may comprise a solid body of Teflon, for example. As will be seen below, because there is no encapsulating material 91 injected under pressure beneath the IC 81, a more compliant mold protrusion 87 may be used than compared, for example, to the embodiments described above using the leadframe 35.

The upper mold portion 86 may be provided as two portions which mate at the illustrated dashed line 88. In other words the upper mold portion 86 may include a changeable cavity plate at the level of the dashed line 88 so that this plate may be changed to accommodate different sized packages as will be appreciated by those skilled in the art.

In this illustrated embodiment, it is further noted that the bleed-through retention channel 90 in the mold protrusion 87 is only along the right hand side of the IC 81. This is so because the encapsulating material 91 will extend onto the

upper surface of the IC **81** to cover the bond pads **82** and bond wires **83** on the right hand side. On the lefthand side it can be seen that the encapsulating material **91** does not extend onto the upper surface, and bleed through of the encapsulating material can be controlled since the mold protrusion **87** extends completely over the upper surface and slightly beyond. Those of skill in the art will appreciate that in other embodiments, the mold protrusion **87** could also be made or configured to have the bleed-through retention channel **90** extend on two, three or all four sides.

The finished IC package **80** is shown in FIG. **10** wherein an upper surface **92** of the IC **81** is exposed through the opening **93** in the encapsulating material **91**. In this illustrated embodiment, the substrate **84** extends outwardly beyond the side edges of the IC **81**. In other embodiments, the side edges of the substrate **84** may be terminated flush with the side edges of the IC **81** as will be appreciated by those skilled in the art. The vestigial portions **95** of encapsulating material **91** are also schematically illustrated by the dashed line on the right hand side of the upper surface **92** of the IC **81**.

It is further noted that although the encapsulating material **91** surrounds the IC **81**, there is no encapsulating material **91** on the back surface of the IC in the illustrated IC package **80**. In this embodiment, the substrate **84** provides the protection for the back surface.

Other aspects of the invention are disclosed in U.S. Patent Application Ser. No. 09/931,587, entitled "METHODS AND APPARATUS FOR MAKING INTEGRATED CIRCUIT PACKAGE INCLUDING OPENING EXPOSING PORTION OF THE IC" file concurrently herewith. The entire contents of this application are incorporated herein by reference. In addition, many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Accordingly, it is understood that the invention is not to be limited to the illustrated embodiments disclosed, and that other modifications and embodiments are intended to be included within the spirit and scope of the appended claims.

That which is claimed is:

1. An integrated circuit package comprising:

an integrated circuit (IC) and encapsulating material surrounding said IC,

said encapsulating material having an opening therein to define an exposed portion of said IC; and

vestigial portions of said encapsulating material on the exposed portion of said IC an spaced inwardly from a periphery of the opening in maid ecapsulating material.

2. An integrated circuit package according to claim **1** wherein the opening in said encapsulating material is generally rectangular; and wherein said vestigial portions of encapsulating material are arranged along at least one side of an imaginary rectangle spaced inwardly from the generally rectangular opening in said encapsulating material.

3. An integrated circuit package according to claim **1** wherein said vestigial portions are spaced inwardly a distance of from 0.1 to 3 mm.

4. An integrated circuit package according to claim **1** further comprising a leadframe carrying said IC.

5. An integrated circuit package according to claim **4** wherein said leadframe comprises a die pad, finger portions, and a plurality of die pad support bars extending between said die pad and said finger portions.

6. An integrated circuit package according to claim **5** wherein said die pad is downset below a level of said finger portions.

7. An integrated circuit package according to claim **6** wherein each of said die pad support bars is resiliently deformed to accommodate the downset of said die pad.

8. An integrated circuit package according to claim **6** further comprising bond wires extending between said IC and the finger portion having a desired clearance from adjacent portions of said IC and an upper surface of said encapsulating material.

9. An integrated circuit package according to claim **5** wherein said die pad has an opening therein.

10. An integrated circuit package according to claim **5** further comprising a low stress, low modulus adhesive securing said IC to said die pad.

11. An integrated circuit package according to claim **1** further comprising a substrate adjacent a back surface of said IC opposite the exposed portion.

12. An integrated circuit package according to claim **1** wherein said substrate covers the back surface of said IC so that said encapsulating material does not extend onto the back surface.

13. An integrated circuit package according to claim **1** wherein said encapsulating material comprises a low stress encapsulating material.

14. An integrated circuit package according to claim **1** wherein said IC comprises upper surface portions with active devices formed therein; and wherein the exposed portion of said IC comprises upper surface portions thereof.

15. An integrated circuit package according to claim **14** wherein the active devices define a sensor.

16. An integrated circuit package according to claim **14** wherein the active devices define an electric field fingerprint sensor.

17. An integrated circuit package comprising:

an integrated circuit (IC) comprising upper surface portions with active devices formed therein and encapsulating material surrounding said IC;

said encapsulating material having an opening therein adjacent the upper surface portions of said IC to define an exposed portion of said IC; and

a leadframe comprising a die pad carrying said IC, finger portions, and a plurality of die pad support bars extending between said die pad and said finger portions;

said die pad being downset below a level of said finger portions.

18. An integrated circuit package according to claim **17** wherein each of said die pad support bars is resiliently deformed to accommodate the downset of said die pad.

19. An integrated circuit package according to claim **18** further comprising bond wires extending between said IC and the finger portion having a desired clearance from adjacent portions of said IC and an upper surface of said encapsulating material.

20. An integrated circuit package according to claim **17** wherein said die pad has an opening therein.

21. An integrated circuit package according to claim **20** further comprising a low stress, low modulus adhesive securing said IC to said die pad.

22. An integrated circuit package according to claim **17** wherein said encapsulating material comprises a low stress encapsulating material.

23. An integrated circuit package according to claim **17** further comprising vestigial portions of encapsulating material on the exposed portion of said IC and spaced inwardly from a periphery of the opening in said encapsulating material.

24. An integrated circuit package according to claim **23** wherein the opening in said encapsulating material is generally rectangular; and wherein said vestigial portions of encapsulating material are arranged along an imaginary rectangle spaced inwardly from the generally rectangular opening in said encapsulating material.

25. An integrated circuit package according to claim **23** wherein said vestigial portions are spaced inwardly a distance of from 0.1 to 3 mm.

26. An integrated circuit package according to claim 17 wherein the active devices define a sensor.

27. An integrated circuit package according to claim 17 wherein the active devices define an electric field fingerprint sensor.

28. An integrated circuit package comprising:

an integrated circuit (IC) comprising upper surface portions with active devices formed therein and encapsulating material surrounding said IC;

said encapsulating material having an opening therein adjacent the upper surface portions of said IC to define an exposed portion of said IC; and

a leadframe comprising a die pad carrying said IC, finger portions, and a plurality of die pad support bars extending between said die pad and said finger portions, each of said die pad support bars being resiliently deformed.

29. An integrated circuit package according to claim 28 wherein said die pad is downset below a level of said finger portions.

30. An integrated circuit package according to claim 29 further comprising bond wires extending between said IC and the finger portion having a desired clearance from adjacent portions of said IC and an upper surface of said encapsulating material.

31. An integrated circuit package according to claim 28 wherein said die pad has an opening therein.

32. An integrated circuit package according to claim 31 further comprising a low stress, low modulus adhesive securing said IC to said die pad.

33. An integrated circuit package according to claim 28 wherein said encapsulating material comprises a low stress encapsulating material.

34. An integrated circuit package according to claim 28 further comprising vestigial portions of encapsulating material on the exposed portion of said IC and spaced inwardly from a periphery of the opening in said encapsulating material.

35. An integrated circuit package according to claim 34 wherein the opening in said encapsulating material is generally rectangular; and wherein said vestigial portions of encapsulating material are arranged along an imaginary rectangle spaced inwardly from the generally rectangular opening in said encapsulating material.

36. An integrated circuit package according to claim 34 wherein said vestigial portions are spaced inwardly a distance of from 0.1 to 3 mm.

37. An integrated circuit package according to claim 28 wherein the active devices define a sensor.

38. An integrated circuit package according to claim 28 wherein the active devices define an electric field fingerprint sensor.

39. An integrated circuit package comprising:

an integrated circuit (IC) comprising upper surface portions with active devices formed therein and encapsulating material surrounding said IC;

said encapsulating material having an opening therein adjacent the upper surface portions of said IC to define an exposed portion of said IC; and

a die pad carrying said IC, said die pad having an opening therein.

40. An integrated circuit package according to claim 39 further comprising finger portions, and a plurality of die pad support bars extending between said die pad and said finger portions, and wherein said die pad is downset below a level of said finger portions.

41. An integrated circuit package according to claim 40 wherein each of said die pad support bars is resilient deformed to accommodate the downset of said die pad.

42. An integrated circuit package according to claim 40 further comprising bond wires extending between said IC and the finger portion having a desired clearance from adjacent portions of said IC and an upper surface of said encapsulating material.

43. An integrated circuit package according to claim 39 further comprising a low stress, low modulus adhesive securing said IC to said die pad.

44. An integrated circuit package according to claim 39 wherein said encapsulating material comprises a low stress encapsulating material.

45. An integrated circuit package according to claim 39 further comprising vestigial portions of encapsulating material on the exposed portion of said IC and spaced inwardly from a periphery of the opening in said encapsulating material.

46. An integrated circuit package according to claim 45 wherein the opening in said encapsulating material is generally rectangular; and wherein said vestigial portions of encapsulating material are arranged along an imaginary rectangle spaced inwardly from the generally rectangular opening in said encapsulating material.

47. An integrated circuit package according to claim 45 wherein said vestigial portions are spaced inwardly a distance of from 0.1 to 3 mm.

48. An integrated circuit package according to claim 39 wherein the active devices define a sensor.

49. An integrated circuit package according to claim 39 wherein the active devices define an electric field fingerprint sensor.

50. An integrated circuit package comprising:

an integrated circuit (IC) and encapsulating material surrounding said IC;

said encapsulating material having an opening therein to define an exposed portion of said IC; and

a substrate covering a back surface of said IC opposite the exposed portion so that said encapsulating material does not extend onto the back surface of said IC.

51. An integrated circuit package according to claim 50 wherein said substrate comprises a printed circuit board.

52. An integrated circuit package according to claim 50 further vestigial portions of encapsulating material on the exposed portion of said IC and spaced inwardly from a periphery of the opening in said encapsulating material.

53. An integrated circuit package according to claim 52 wherein the opening in said encapsulating material is generally rectangular; and wherein said vestigial portions of encapsulating material are arranged along at least one side of an imaginary rectangle spaced inwardly from the generally rectangular opening in said encapsulating material.

54. An integrated circuit package according to claim 52 wherein said vestigial portions are spaced inwardly a distance of from 0.1 to 3 mm.

55. An integrated circuit package according to claim 52 wherein said encapsulating material comprises a low stress encapsulating material.

56. An integrated circuit package according to claim 52 wherein said IC comprises upper surface portions with active devices formed therein; and wherein the exposed portion of said IC comprises upper surface portions thereof.

57. An integrated circuit package according to claim 56 wherein the active devices define a sensor.

58. An integrated circuit package according to claim 57 wherein the active devices define an electric field fingerprint sensor.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,667,439 B2
APPLICATION NO. : 09/931378
DATED : December 23, 2003
INVENTOR(S) : Salatino et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 9, Line 46	Delete: “an spaced” Insert: -- and spaced --
Column 9, Line 47	Delete: “maid” Insert: -- said --

Signed and Sealed this

Thirtieth Day of January, 2007

JON W. DUDAS
Director of the United States Patent and Trademark Office

EXHIBIT C

US005940526A

United States Patent [19]

Setlak et al.

[11] Patent Number: 5,940,526

[45] Date of Patent: Aug. 17, 1999

[54] ELECTRIC FIELD FINGERPRINT SENSOR HAVING ENHANCED FEATURES AND RELATED METHODS

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[73] Assignee: Harris Corporation, Palm Bay, Fla.

[21] Appl. No.: 08/858,144

[22] Filed: May 16, 1997

[51] Int. Cl.[6] G06K 9/00

[52] U.S. Cl. 382/124

[58] Field of Search 382/124–127, 382/324; 348/294; 257/414, 428, 434, 446, 448, 758, 659, 355; 250/370.01, 370.08, 553; 340/825.34

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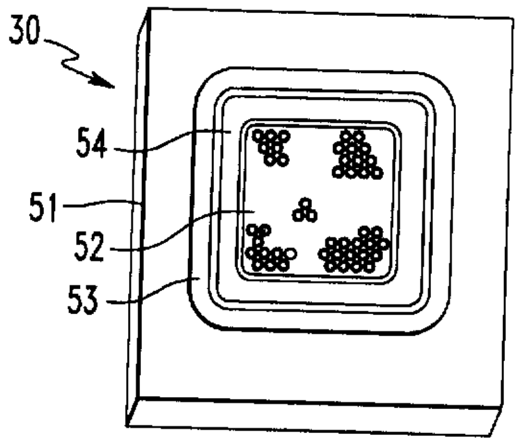
Primary Examiner—Leo H. Boudreau
Assistant Examiner—Dmitry A. Novik
Attorney, Agent, or Firm—Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A.

[57] ABSTRACT

A fingerprint sensor includes a plurality of semiconductor devices adjacent a substrate and defining active circuit portions, and having only three metal layers. More particularly, the sensor may include a first metal layer interconnecting predetermined ones of the plurality of semiconductor devices; a second metal layer defining a ground plane; and a third metal layer comprising an array of electric field sensing electrodes connected to active circuit portions for generating an output related to a sensed fingerprint. The fingerprint sensor may also include a package surrounding the substrate and having an opening aligned with the sensing electrodes. In addition, a first external electrode may be carried by the package for contact by a finger. The sensor may thus also include an excitation drive circuit connected between the ground plane and the first external electrode for generating electric fields between the electric field sensing electrodes and adjacent finger portions. A power control circuit is for controlling operation of active circuit portions based upon sensing finger contact with the first external electrode so that the active circuit portions are powered upon sensing finger contact with the first external electrode and otherwise grounded. A second external electrode may be connected to a bleed resistor to bleed charge from the finger prior to switching from the grounded to the powered state. An amplifier connected between each electric field sensing electrode and associated shield electrode may be operated at a gain of greater than one for additional noise rejection.

36 Claims, 6 Drawing Sheets



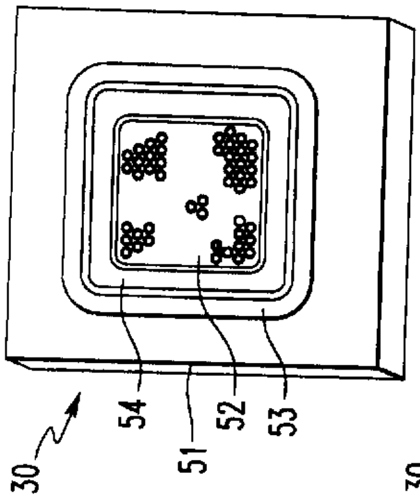

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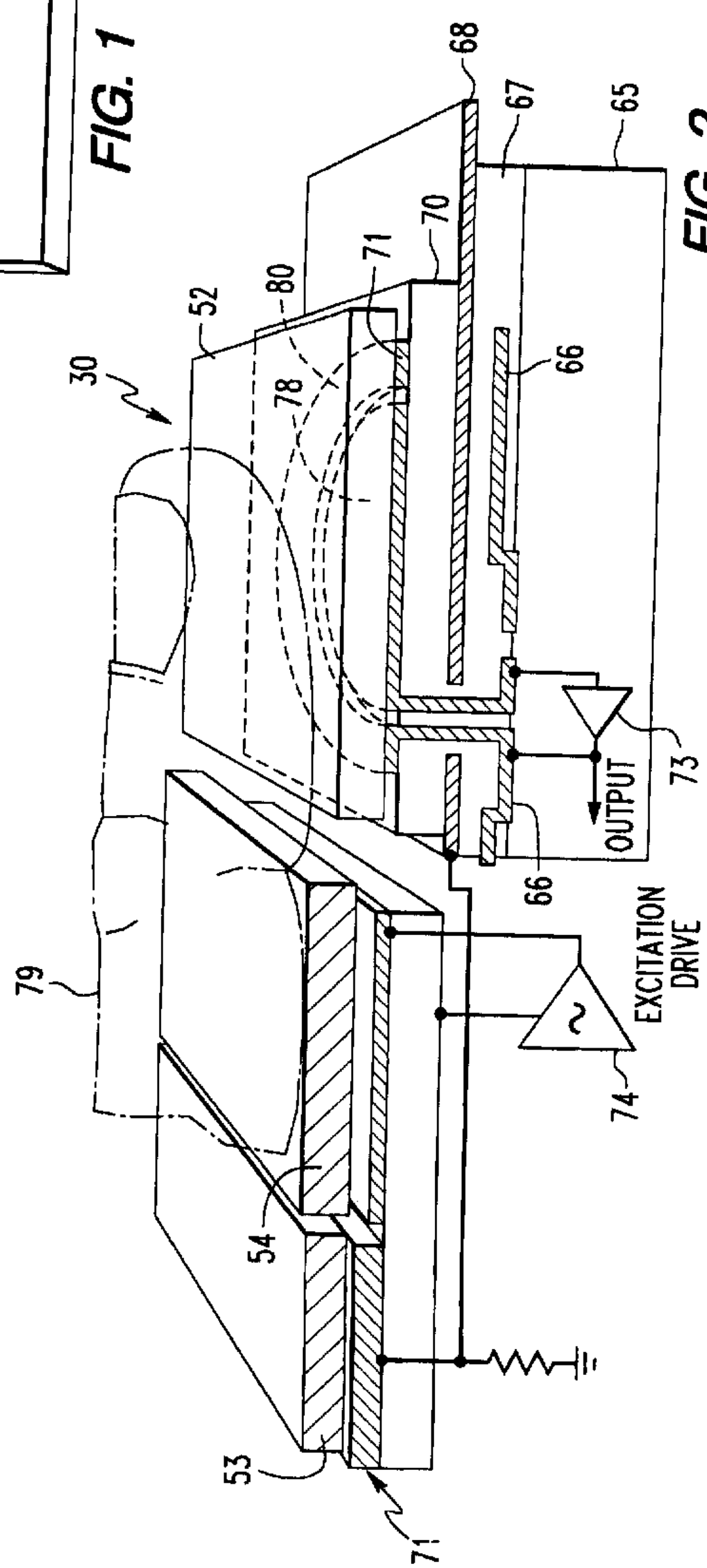
FIG. 1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OUTPUT
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EXCITATION
DRIVE
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FIG. 2

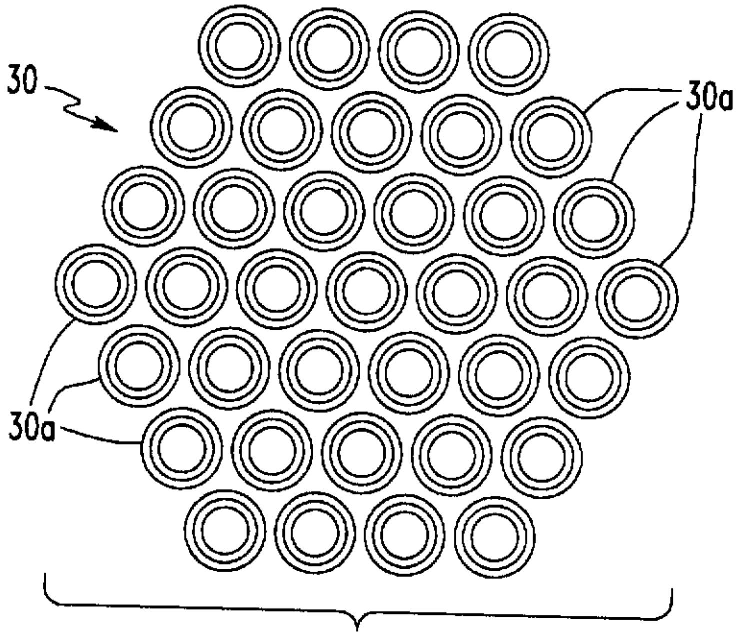
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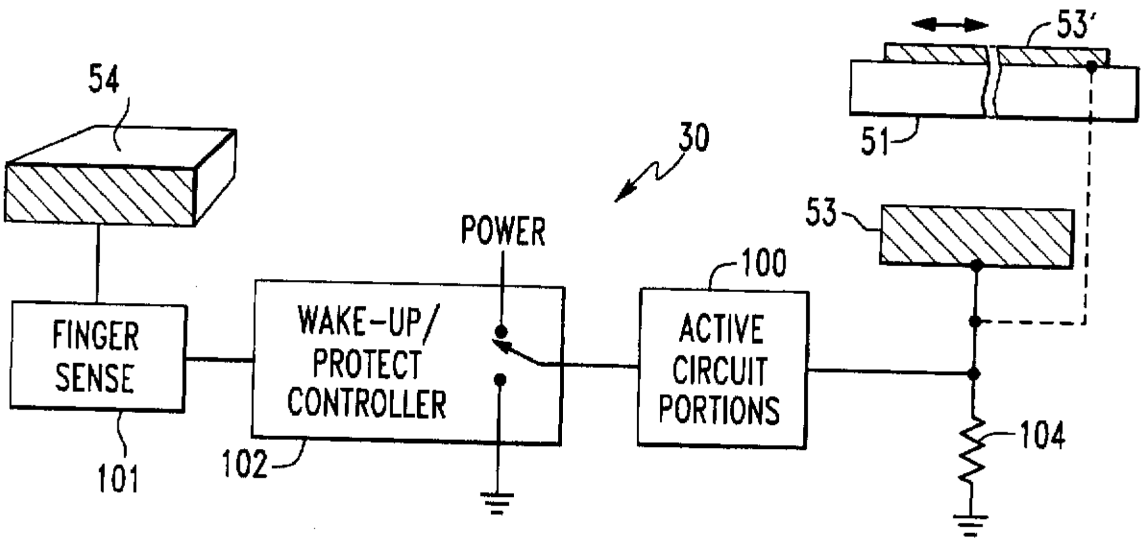
FIG.3


54
FINGER SENSE
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WAKE-UP/ PROTECT CONTROLLER
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POWER
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ACTIVE CIRCUIT PORTIONS
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53'
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FIG.4

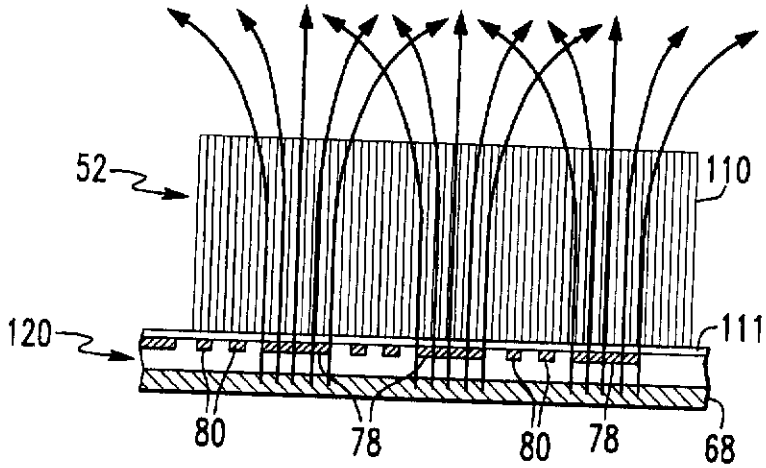

FIG. 5

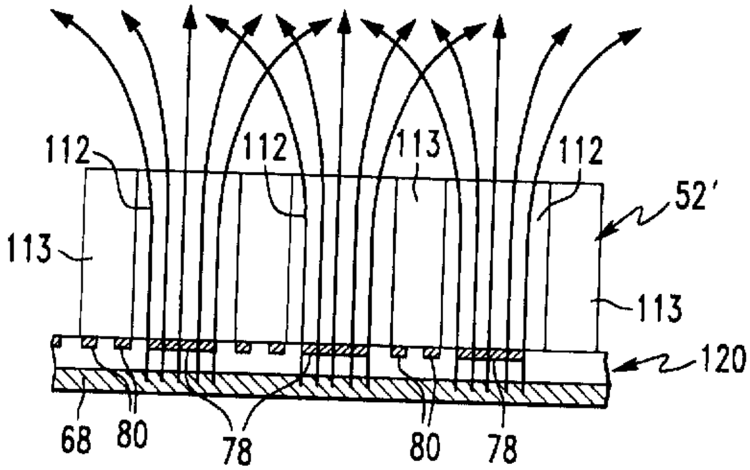

FIG. 6

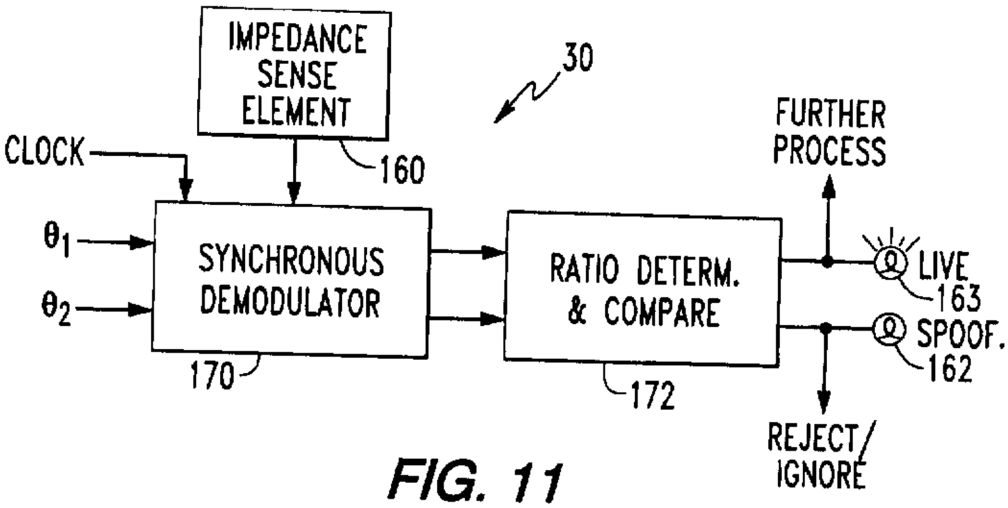

FIG. 11

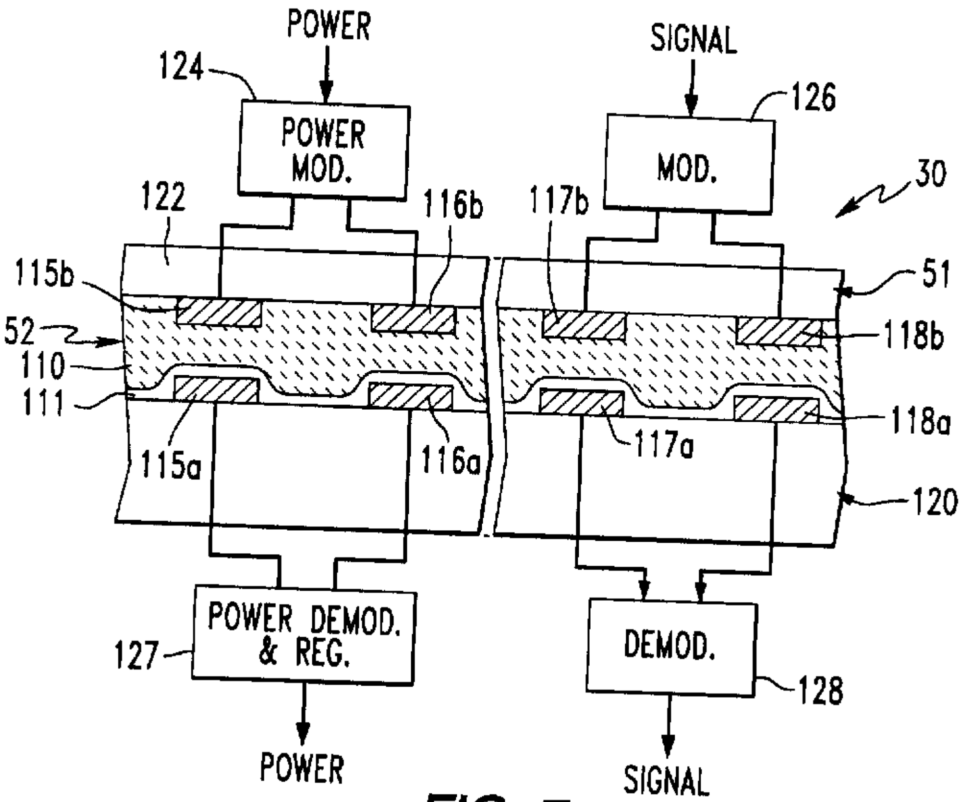
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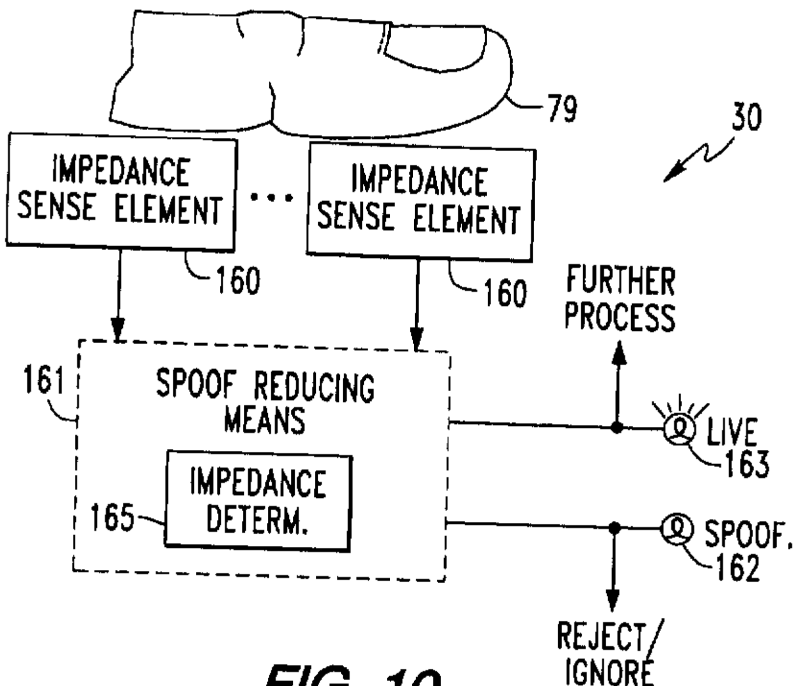
FIG. 7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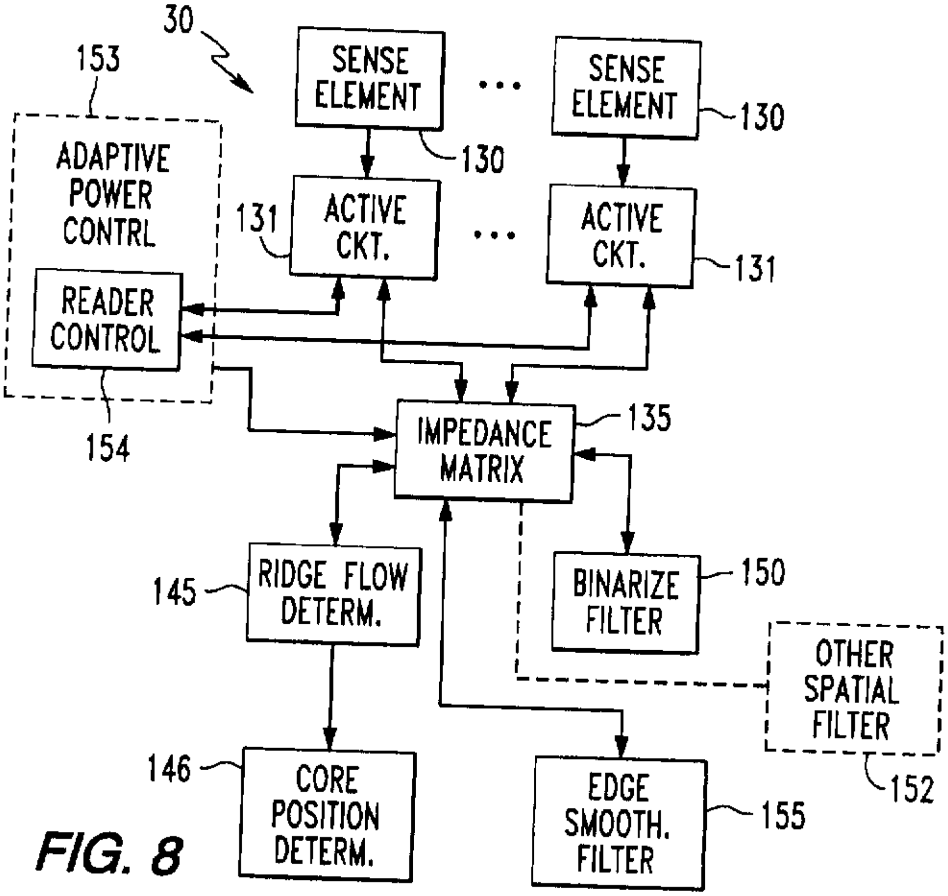
REJECT/ IGNORE

FIG. 10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SENSE ELEMENT
SENSE ELEMENT
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ADAPTIVE POWER CONTRL
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ACTIVE CKT.
ACTIVE CKT.
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READER CONTROL
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IMPEDANCE MATRIX
135
145
RIDGE FLOW DETERM.
BINARIZE FILTER
150
OTHER SPATIAL FILTER
152
146
CORE POSITION DETERM.
EDGE SMOOTH. FILTER
155

FIG. 8

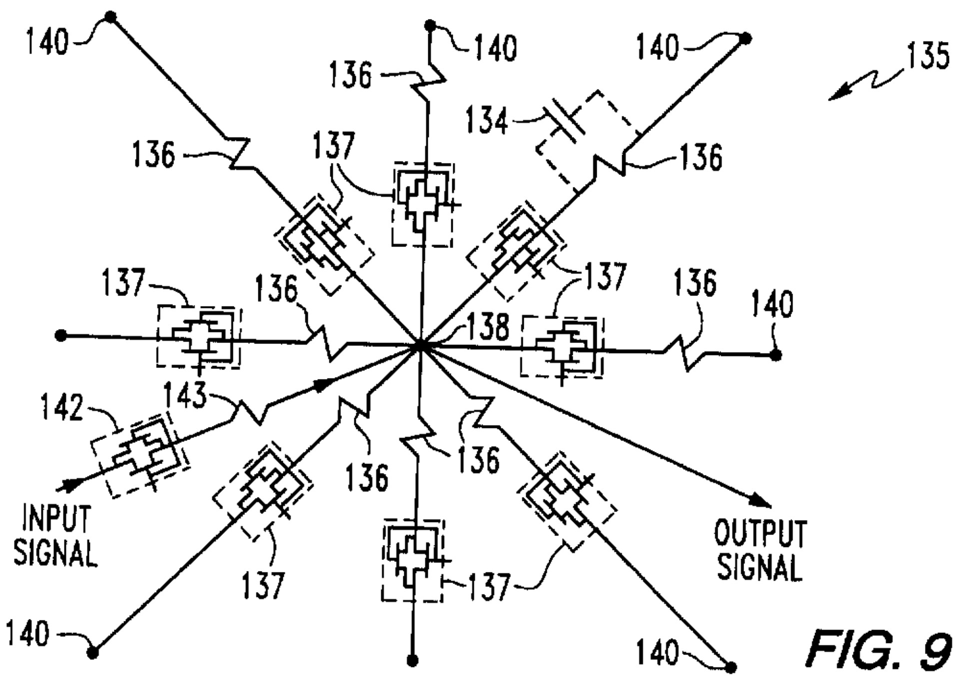
140
140
140
135
136
134
136
136
137
136
137
137
136
140
138
142
143
INPUT SIGNAL
136
136
137
137
OUTPUT SIGNAL
140
140

FIG. 9

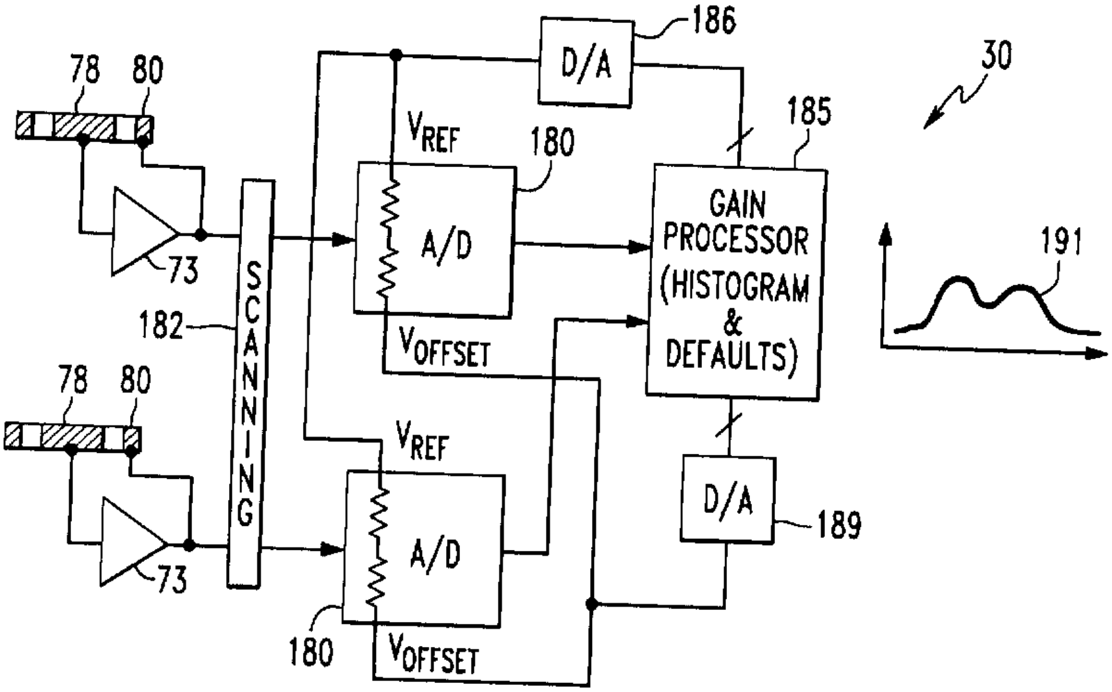
186
30
78 80
D/A
185
V_REF
180
GAIN PROCESSOR (HISTOGRAM & DEFAULTS)
A/D
191
73
182
SCANNING
V_OFFSET
78 80
V_REF
D/A
189
A/D
73
180
V_OFFSET

FIG. 12

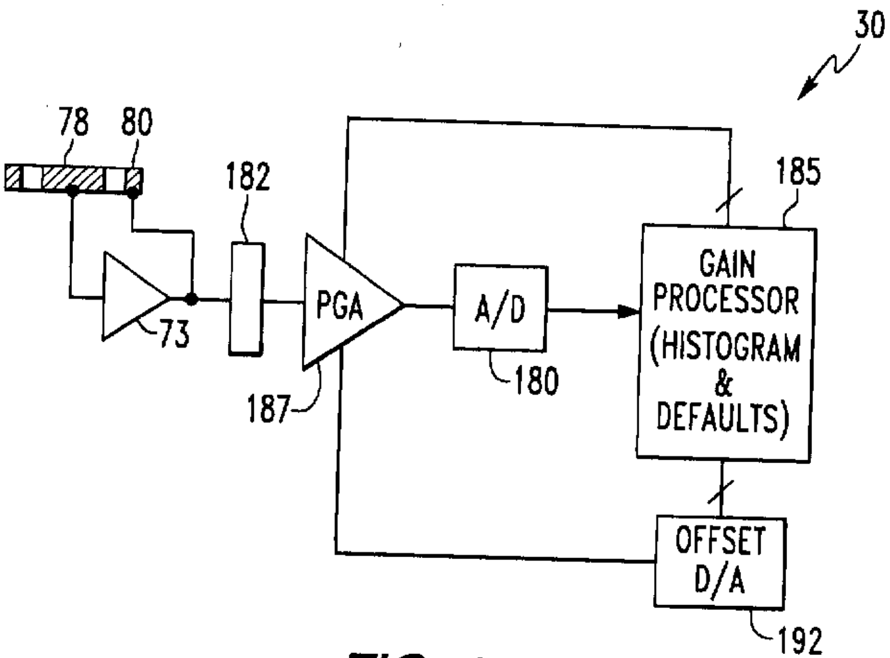
30
78 80
185
182
PGA
A/D
GAIN PROCESSOR (HISTOGRAM & DEFAULTS)
73
180
187
OFFSET D/A
192

FIG. 13

ELECTRIC FIELD FINGERPRINT SENSOR HAVING ENHANCED FEATURES AND RELATED METHODS

FIELD OF THE INVENTION

The present invention relates to the field of personal identification and verification, and, more particularly, to the field of fingerprint sensing and processing.

BACKGROUND OF THE INVENTION

Fingerprint sensing and matching is a reliable and widely used technique for personal identification or verification. In particular, a common approach to fingerprint identification involves scanning a sample fingerprint or an image thereof and storing the image and/or unique characteristics of the fingerprint image. The characteristics of a sample fingerprint may be compared to information for reference fingerprints already in a database to determine proper identification of a person, such as for verification purposes.

A typical electronic fingerprint sensor is based upon illuminating the finger surface using visible light, infrared light, or ultrasonic radiation. The reflected energy is captured with some form of camera, for example, and the resulting image is framed, digitized and stored as a static digital image. For example, U.S. Pat. No. 4,210,899 to Swonger et al. discloses an optical scanning fingerprint reader cooperating with a central processing station for a secure access application, such as admitting a person to a location or providing access to a computer terminal. U.S. Pat. No. 4,525,859 to Bowles similarly discloses a video camera for capturing a fingerprint image and uses the minutiae of the fingerprints, that is, the branches and endings of the fingerprint ridges, to determine a match with a database of reference fingerprints.

Unfortunately, optical sensing may be affected by stained fingers or an optical sensor may be deceived by presentation of a photograph or printed image of a fingerprint rather than a true live fingerprint. In addition, optical schemes may require relatively large spacings between the finger contact surface and associated imaging components. Moreover, such sensors typically require precise alignment and complex scanning of optical beams. Accordingly, optical sensors may thus be bulky and be susceptible to shock, vibration and surface contamination. Accordingly, an optical fingerprint sensor may be unreliable in service in addition to being bulky and relatively expensive due to optics and moving parts.

U.S. Pat. No. 4,353,056 to Tsikos discloses another approach to sensing a live fingerprint. In particular, the patent discloses an array of extremely small capacitors located in a plane parallel to the sensing surface of the device. When a finger touches the sensing surface and deforms the surface, a voltage distribution in a series connection of the capacitors may change. The voltages on each of the capacitors is determined by multiplexor techniques. Unfortunately, the resilient materials required for the sensor may suffer from long term reliability problems. In addition, multiplexing techniques for driving and scanning each of the individual capacitors may be relatively slow and cumbersome. Moreover, noise and stray capacitances may adversely affect the plurality of relatively small and closely spaced capacitors.

U.S. Pat. No. 5,325,442 to Knapp discloses a fingerprint sensor including a plurality of sensing electrodes. Active addressing of the sensing electrodes is made possible by the provision of a switching device associated with each sensing

electrode. A capacitor is effectively formed by each sensing electrode in combination with the respective overlying portion of the finger surface which, in turn, is at ground potential. The sensor may be fabricated using semiconductor wafer and integrated circuit technology. The dielectric material upon which the finger is placed may be provided by silicon nitride or a polyimide which may be provided as a continuous layer over an array of sensing electrodes. Further conductors may be provided on the surface of the dielectric material remote from the sensing electrodes and extending over regions between the sensing electrodes, for example, as lines or in grid form, which conductors are grounded in order to improve the electrical contact to the finger surface.

Unfortunately, driving the array of closely spaced sensing electrodes as disclosed in the Knapp et al. patent may be difficult since adjacent electrodes may affect one another. Another difficulty with such a sensor may be its ability to distinguish ridges and valleys of a fingerprint when the conductivity of the skin and any contaminants may vary widely from person-to-person and even over a single fingerprint. Yet another difficulty with such a sensor, as with many optical sensors, is that different portions of the fingerprint may require relatively complicated post image collection processing to provide for usable signal levels and contrast to thereby permit accurate determination of the ridges and valleys of the fingerprint. For example, U.S. Pat. No. 4,811,414 to Fishbine et al. discloses methods for noise averaging, illumination equalizing, directional filtering, curvature correcting, and scale correcting for an optically generated fingerprint image. Unfortunately, the various processing steps are complex and require considerable computational power in a downstream processor. Signal processing of other fingerprint circuits may also be relatively complicated and therefore expensive and/or slow.

Greater advances in fingerprint sensing and matching for identification and verification are desirable for many applications. Unfortunately, current sensors and their associated circuitry may be too bulky, expensive and unreliable for a great many applications which would otherwise benefit from fingerprint identification and verification technology. Conventional sensors typically consume relatively large amounts of power and may also be susceptible to damage from electrostatic discharges (ESD).

SUMMARY OF THE INVENTION

In view of the foregoing background, it is therefore an object of the present invention to provide a fingerprint sensor and associated methods which is relatively inexpensive, robust, and which is energy efficient.

This and other objects, advantages, and features of the present invention are provided by one embodiment of a fingerprint sensor including a plurality of semiconductor devices adjacent a substrate and defining active circuit portions, and having only three metal layers. More particularly, the sensor may include a first metal layer interconnecting predetermined ones of the plurality of semiconductor devices; a second metal layer adjacent the first dielectric layer defining a ground plane; and a third metal layer comprising an array of electric field sensing electrodes connected to active circuit portions for generating signals related to a sensed fingerprint. Intervening first and second dielectric layers may be positioned between the first and second, and second and third metal layers, respectively. A third dielectric layer may also be provided adjacent the third metal layer.

The fingerprint sensor may also include a package surrounding the substrate and having an opening aligned with

the array of electric field sensing electrodes. In addition, a first external electrode may be carried by the package for contact by a finger. The sensor may thus also include excitation drive means connected between the ground plane and the first external electrode for generating electric fields between the electric field sensing electrodes and adjacent finger portions.

One important aspect of the invention is the provision of power control means for controlling operation of active circuit portions based upon sensing finger contact with the first external electrode. The power control means may include wake-up means for only powering active circuit portions upon sensing finger contact with the first external electrode to thereby conserve power. Alternately or additionally, the power control means may further comprise protection means for grounding active circuit portions upon not sensing finger contact with the first external electrode.

Moreover, the fingerprint sensor may further comprise finger charge bleed means for bleeding a charge from a finger upon contact therewith. The finger charge bleed means may be provided by a second external electrode carried by the package for contact by a finger, and a charge bleed resistor connected between the second external electrode and an earth ground. In addition, the finger charge bleed means and power control means may be such that the active portions remain grounded until the charge bleed means can remove the charge on the finger before powering the active circuit portions. Accordingly, power may be conserved in the sensor and ESD protection provided by the sensor so that the sensor is relatively inexpensive, yet robust and conserves power.

To provide additional noise rejection, the sensor may include pairs of electric field sensing electrodes and associated shield electrodes. In addition, an amplifier may be connected between each pair. Moreover, each amplifier may be operated at an amplification gain of greater than about one to thereby provide additional noise rejection.

A method aspect of the invention is for making a fingerprint sensor. The method preferably comprises the steps of: forming a plurality of semiconductor devices adjacent a substrate and defining active circuit portions; forming a first metal layer interconnecting predetermined ones of the plurality of semiconductor devices; forming a first dielectric layer adjacent the first metal layer; forming a second metal layer adjacent the first dielectric layer defining a ground plane; forming a second dielectric layer adjacent the second metal layer; and forming a third metal layer adjacent the second dielectric layer and comprising an array of electric field sensing electrodes connected to active circuit portions for generating signals related to a sensed fingerprint.

Another method aspect of the invention is for controlling operation of a fingerprint sensor of a type comprising a plurality of semiconductor devices adjacent a substrate and defining active circuit portions for generating an output related to a sensed fingerprint, a package surrounding the substrate, and a first external electrode carried by the package for contact by a finger. This method preferably comprises the steps of: only powering active circuit portions upon sensing finger contact with the first external electrode to thereby conserve power, and grounding active circuit portions upon not sensing finger contact with the first external electrode. The method may further include the step of bleeding a charge from the finger upon initial contact of the finger with the fingerprint package and before switching from grounding of the active circuit portions to powering same.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a top plan view of a fingerprint sensor in accordance with the present invention.

FIG. **2** is a schematic view of a circuit portion of the fingerprint sensor as shown in FIG. **1**.

FIG. **3** is a greatly enlarged top plan view of the sensing portion of the fingerprint sensor as shown in FIG. **1**.

FIG. **4** is a schematic diagram of another circuit portion of the fingerprint sensor as shown in FIG. **1**.

FIG. **5** is a greatly enlarged side cross-sectional view of a portion of the fingerprint sensor as shown in FIG. **1**.

FIG. **6** is a greatly enlarged side cross-sectional view of a portion of an alternate embodiment of the fingerprint sensor in accordance with the invention.

FIG. **7** is a greatly enlarged side cross-sectional view of another portion of the fingerprint sensor as shown in FIG. **1**.

FIG. **8** is a schematic block diagram of yet another circuit portion of the fingerprint sensor as shown in FIG. **1**.

FIG. **9** is a schematic circuit diagram of a portion of the circuit as shown in FIG. **8**.

FIG. **10** is a schematic block diagram of still another circuit portion of the fingerprint sensor as shown in FIG. **1**.

FIG. **11** is a schematic block diagram of an alternate embodiment of the circuit portion shown in FIG. **10**.

FIG. **12** is a schematic block diagram of an additional circuit portion of the fingerprint sensor as shown in FIG. **1**.

FIG. **13** is a schematic block diagram of an alternate embodiment of the circuit portion shown in FIG. **12**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout. The scaling of various features, particularly layers in the drawing figures, have been exaggerated for clarity of explanation.

Referring to FIGS. **1–3**, the fingerprint sensor **30** in accordance with the invention is initially described. The illustrated sensor **30** includes a housing or package **51**, a dielectric layer **52** exposed on an upper surface of the package which provides a placement surface for the finger, and a plurality of output pins, not shown. A first conductive strip or external electrode **54** around the periphery of the dielectric layer **52**, and a second external electrode **53** provide contact electrodes for the finger **79** as described in greater detail below. The sensor **30** may provide output signals in a range of sophistication levels depending on the level of processing incorporated in the package as would be readily understood by those skilled in the art.

The sensor **30** includes a plurality of individual pixels or sensing elements **30***a* arranged in array pattern as perhaps best shown in FIG. **3**. As would be readily understood by those skilled in the art, these sensing elements are relatively small so as to be capable of sensing the ridges **59** and intervening valleys **60** of a typical fingerprint. As will also be readily appreciated by those skilled in the art, live fingerprint readings as from the electric field sensor **30** in

accordance with the present invention may be more reliable than optical sensing, because the impedance of the skin of a finger in a pattern of ridges and valleys is extremely difficult to simulate. In contrast, an optical sensor may be deceived by a readily deceived by a photograph or other similar image of a fingerprint, for example.

The sensor **30** includes a substrate **65**, and one or more active semiconductor devices formed thereon, such as the schematically illustrated amplifier **73**. A first metal layer **66** interconnects the active semiconductor devices. A second or ground plane electrode layer **68** is above the first metal layer **66** and separated therefrom by an insulating layer **67**. A third metal layer **71** is positioned over another dielectric layer **70**. In the illustrated embodiment, the first external electrode **54** is connected to an excitation drive amplifier **74** which, in turn, drives the finger **79** with a signal may be typically in the range of about 1 KHz to 1 MHz. Accordingly, the drive or excitation electronics are thus relatively uncomplicated and the overall cost of the sensor **30** may be relatively low, while the reliability is great.

An illustratively circularly shaped electric field sensing electrode **78** is on the insulating layer **70**. The sensing electrode **78** may be connected to sensing integrated electronics, such as the illustrated amplifier **73** formed adjacent the substrate **65** as schematically illustrated, and as would be readily appreciated by those skilled in the art.

An annularly shaped shield electrode **80** surrounds the sensing electrode **78** in spaced relation therefrom. As would be readily appreciated by those skilled in the art, the sensing electrode **78** and its surrounding shield electrode **80** may have other shapes, such as hexagonal, for example, to facilitate a close packed arrangement or array of pixels or sensing elements **30a**. The shield electrode **80** is an active shield which is driven by a portion of the output of the amplifier **73** to help focus the electric field energy and, moreover, to thereby reduce the need to drive adjacent electric field sensing electrodes **78**.

The sensor **30** includes only three metal or electrically conductive layers **66**, **68** and **71**. The sensor **30** can be made without requiring additional metal layers which would otherwise increase the manufacturing cost, and, perhaps, reduce yields. Accordingly, the sensor **30** is less expensive and may be more rugged and reliable than a sensor including four or more metal layers as would be appreciated by those skilled in the art.

Another important aspect of the present invention is that the amplifier **73** may be operated at a gain of greater than about one to drive the shield electrode **80**. Stability problems do not adversely affect the operation of the amplifier **73**. Moreover, the common mode and general noise rejection are greatly enhanced according to this feature of the invention. In addition, the gain greater than one tends to focus the electric field with resect to the sensing electrode **78** as will be readily appreciated by those skilled in the art.

In general, the sensing elements **30a** operate at very low currents and at very high impedances. For example, the output signal from each sensing electrode **78** is desirably about 5 to 10 millivolts to reduce the effects of noise and permit further processing of the signals. The approximate diameter of each sensing element **30a**, as defined by the outer dimensions of the shield electrode **80**, may be about 0.002 to 0.005 inches in diameter. The ground plane electrode **68** protects the active electronic devices from unwanted excitation. The various signal feedthrough conductors for the electrodes **78**, **80** to the active electronic circuitry may be readily formed as would be understood by those skilled in the art.

The overall contact or sensing surface for the sensor **30** may desirably be about 0.5 by 0.5 inches — a size which may be readily manufactured and still provide a sufficiently large surface for accurate fingerprint sensing and identification. The sensor **30** in accordance with the invention is also fairly tolerant of dead pixels or sensing elements **30a**. A typical sensor **30** includes an array of about 256 by 256 pixels or sensor elements, although other array sizes are also contemplated by the present invention. The sensor **30** may also be fabricated at one time using primarily conventional semiconductor manufacturing techniques to thereby significantly reduce the manufacturing costs.

Turning now additionally to FIG. **4**, another aspect of the sensor **30** of the invention is described. The sensor may include power control means for controlling operation of active circuit portions **100** based upon sensing finger contact with the first external electrode **54** as determined by the illustrated finger sense block or circuit **101**. For example, the finger sense circuit **101** may operate based upon a change in impedance to an oscillator to thereby determine finger contact. Of course, other approaches for sensing contact with the finger are also contemplated by the invention. The power control means may include wake-up means for only powering active circuit portions upon sensing finger contact with the first external electrode to thereby conserve power. Alternately or additionally, the power control means may further comprise protection means for grounding active circuit portions upon not sensing finger contact with the first external electrode. In the illustrated embodiment, a combination of wake-up and protection controller circuits **102** are illustrated.

Moreover, the fingerprint sensor **30** may further comprise finger charge bleed means for bleeding a charge from a finger or other object upon contact therewith. The finger charge bleed means may be provided by the second external electrode **53** carried by the package **51** for contact by a finger, and a charge bleed resistor **104** connected between the second external electrode and an earth ground. As schematically illustrated in the upper right hand portion of FIG. **4**, the second electrode may alternately be provided by a movable electrically conductive cover **53'** slidably connected to the package **51** for covering the opening to the exposed upper dielectric layer **52**. A pivotally connected cover is also contemplated by the present invention. Accordingly, under normal conditions, the charge would be bled from the finger as the cover **53'** is moved to expose the sensing portion of the sensor **30**.

In addition, the finger charge bleed means and power control means may be such that the active portions remain grounded until the charge bleed means can remove the charge on the finger before powering the active circuit portions, such as by providing a brief delay during wake-up sufficient to permit the charge to be discharged through the resistor **104** as would be readily understood by those skilled in the art. Accordingly, power may be conserved in the sensor **30** and ESD protection provided by the sensor so that the sensor is relatively inexpensive, yet robust and conserves power.

Referring now additionally to FIG. **5** yet another significant feature of the sensor **30** is described. The dielectric covering **52** may preferably comprise a z-axis anisotropic dielectric layer **110** for focussing an electric field, shown by the illustrated field lines, at each of the electric field sensing electrodes **78**. In other words, the dielectric layer **110** may be relatively thick, but not result in defocussing of the electric fields propagating therethrough because of the z-axis anisotropy of the material. Typically there would be a trade-off

between field focus and mechanical protection. Unfortunately, a thin film which is desirable for focussing, may permit the underlying circuit to be more easily subject to damage.

The z-axis anisotropic dielectric layer **110** of the present invention, for example, may have a thickness in range of about 0.0001 to 0.004 inches. Of course, the z-axis anisotropic dielectric layer **110** is also preferably chemically resistant and mechanically strong to withstand contact with fingers, and to permit periodic cleanings with solvents. The z-axis anisotropic dielectric layer **110** may preferably define an outermost protective surface for the integrated circuit die **120**. Accordingly, the overall dielectric covering **52** may further include at least one relatively thin oxide, nitride, carbide, or diamond layer **111** on the integrated circuit die **120** and beneath the z-axis anisotropic dielectric layer **110**. The thin layer **111** will typically be relatively hard, and the z-axis anisotropic dielectric layer **110** is desirably softer to thereby absorb more mechanical activity.

The z-axis anisotropic dielectric layer **110** may be provided by a plurality of oriented dielectric particles in a cured matrix. For example, the z-axis anisotropic dielectric layer **110** may comprise barium titanate in a polyimide matrix. Those of skill in the art will appreciate other materials exhibiting z-axis anisotropy suitable for the present invention. For example, certain ceramics exhibit dielectric anisotropy as would also be appreciated by those skilled in the art.

Turning to FIG. **6**, another variation of a z-axis dielectric covering **52'** is schematically shown by a plurality of high dielectric portions **112** aligned with corresponding electric field sensing electrodes **78**, and a surrounding matrix of lower dielectric portions **113**. This embodiment of the dielectric covering **52'** may be formed in a number of ways, such as by forming a layer of either the high dielectric or low dielectric portions, selectively etching same, and filling the openings with the opposite material. Another approach may be to use polarizable microcapsules and subjecting same to an electric field during curing of a matrix material. A material may be compressed to cause the z-axis anisotropy. Laser and other selective processing techniques may also be used as would be readily understood by those skilled in the art.

Another aspect of the invention relates to being able to completely cover and protect the entire upper surface of the integrated circuit die **120**, and still permit connection and communication with the external devices and circuits as now further explained with reference to FIG. **7**. The third metal layer **71** (FIG. **2**) preferably further includes a plurality of capacitive coupling pads **116a–118a** for permitting capacitive coupling of the integrated circuit die **120**. Accordingly, the dielectric covering **52** is preferably continuous over the capacitive coupling pads **116a–118a** and the array of electric field sensing electrodes **78** of the pixels **30a** (FIG. **1**). In sharp contrast to this feature of the present invention, it is conventional to create openings through an outer coating to electrically connect to the bond pads. Unfortunately, these openings would provide pathways for water and/or other contaminants to come in contact with and damage the die.

A portion of the package **51** includes a printed circuit board **122** which carries corresponding pads **115b–118b**. A power modulation circuit **124** is coupled to pads **115b–116b**, while a signal modulation circuit **126** is illustrative coupled to pads **117b–118b**. As would be readily understood by those skilled in the art, both power and signals may be readily coupled between the printed circuit board **122** and the integrated circuit die **120**, further using the illustrated power

demodulation/regulator circuit **127**, and the signal demodulation circuit **128**. The z-axis anisotropic dielectric layer **110** also advantageously reduces cross-talk between adjacent capacitive coupling pads. This embodiment of the invention **30** presents no penetrations through the dielectric covering **52** for moisture to enter and damage the integrated circuit die **120**. In addition, another level of insulation is provided between the integrated circuit and the external environment.

For the illustrated fingerprint sensor **30**, the package **51** preferably has an opening aligned with the array of electric field sensing electrodes **78** (FIGS. **1–3**). The capacitive coupling and z-axis anisotropic layer **110** may be advantageously used in a number of applications in addition to the illustrated fingerprint sensor **30**, and particularly where it is desired to have a continuous film covering the upper surface of the integrated circuit die **120** and pads **116a–118a**.

Further aspects of the manufacturing of the sensor **30** including the z-axis anisotropic dielectric material are explained in U.S. patent application Ser. No. 08/857,525 filed May 16, 1997, entitled "Direct Chip Attachment Method and Devices Produced Thereby". This patent application has attorney work docket no. 18763, is assigned to the present assignee, and the entire disclosure of which is incorporated herein by reference.

Referring additionally to FIGS. **8** and **9**, impedance matrix filtering aspects of the invention are now described. As shown in FIG. **8**, the fingerprint sensor **30** may be considered as comprising an array of fingerprint sensing elements **130** and associated active circuits **131** for generating signals relating to the fingerprint image. The illustrated sensor **30** also includes an impedance matrix **135** connected to the active circuits for filtering the signals therefrom.

As shown with more particular reference to FIG. **9**, the impedance matrix **135** includes a plurality of impedance elements **136** with a respective impedance element connectable between each active circuit of a respective fingerprint sensing element as indicated by the central node **138**, and the other active circuits (outer nodes **140**). The impedance matrix **135** also includes a plurality of switches **137** with a respective switch connected in series with each impedance element **136**. An input signal may be supplied to the central node **138** via the illustrated switch **142** and its associated impedance element **143**. The impedance element may one or more of a resistor as illustrated, and a capacitor **134** as would be readily appreciated by those skilled in the art.

Filter control means may operate the switches **137** to perform processing of the signals generated by the active circuits **131**. In one embodiment, the fingerprint sensing elements **130** may be electric field sensing electrodes **78**, and the active circuits **131** may be amplifiers **73** (FIG. **2**). Of course other sensing elements and active circuits may also benefit from the impedance matrix filtering of the present invention as would be readily understood by those skilled in the art.

Ridge flow determining means **145** may be provided for selectively operating the switches **137** of the matrix **135** to determine ridge flow directions of the fingerprint image. More particularly, the ridge flow determining means **145** may selectively operate the switches **137** for determining signal strength vectors relating to ridge flow directions of the fingerprint image. As would be readily understood by those skilled in the art, the ridge flow directions may be determined based upon well known rotating slit principles.

The sensor **30** may include core location determining means **146** cooperating with the ridge flow determining means **145** for determining a core location of the fingerprint

image. The position of the core is helpful, for example, in extracting and processing minutiae from the fingerprint image as would also be readily understood by those skilled in the art.

As also schematically illustrated in FIG. **8**, a binarizing filter **150** may be provided for selectively operating the switches **137** to convert a gray scale fingerprint image to a binarized fingerprint image. Considered another way, the impedance matrix **135** may be used to provide dynamic image contrast enhancement. In addition, an edge smoothing filter **155** may be readily implemented to improve the image. As also schematically illustrated other spatial filters **152** may also be implemented using the impedance matrix **135** for selectively operating the switches **137** to spatially filter the fingerprint image as would be readily appreciated by those of skill in the art. Accordingly, processing of the fingerprint image may be carried out at the sensor **30** and thereby reduce additional downstream computational requirements.

As shown in the illustrated embodiment of FIG. **9**, the impedance matrix **135** may comprise a plurality of impedance elements with a respective impedance element **136** connectable between each active circuit for a given fingerprint sensing element **130** and eight other active circuits for respective adjacent fingerprint sensing elements.

Yet another aspect of the invention is the provision of control means **153** for sequentially powering sets of active circuits **131** to thereby conserve power. Of course, the respective impedance elements **136** are desirably also sequentially connected to perform the filtering function. The powered active circuits **131** may be considered as defining a cloud or kernel as would be readily appreciated by those skilled in the art. The power control means **153** may be operated in an adaptive fashion whereby the size of the area used for filtering is dynamically changed for preferred image characteristics as would also be readily understood by those skilled in the art. In addition, the power control means **153** may also power only certain ones of the active circuits corresponding to a predetermined area of the array of sensing elements **130**. For example, every other active circuit **131** could be powered to thereby provide a larger area, but reduced power consumption as would also be understood by those skilled in the art.

Reader control means **154** may be provided to read only predetermined subsets of each set of active circuits **131** so that a contribution from adjacent active circuits is used for filtering. In other words, only a subset of active circuits **131** are typically simultaneously read although adjacent active circuits **131** and associated impedance elements **136** are also powered and connected, respectively. For example, **16** impedance elements **136** could define a subset and be readily simultaneously read. The subset size could be optimized for different sized features to be determined as would be readily appreciated by those skilled in the art.

Accordingly, the array of sense elements **130** can be quickly read, and power consumption substantially reduced since all of the active circuits **131** need not be powered for reading a given set of active circuits. For a typical sensor, the combination of the power control and impedance matrix features described herein may permit power savings by a factor of about 10 as compared to powering the full array.

It is another important advantage of the fingerprint sensor **30** according to present invention to guard against spoofing or deception of the sensor into incorrectly treating a simulated image as a live fingerprint image. For example, optical sensors may be deceived or spoofed by using a paper with a fingerprint image thereon. The unique electric field sensing

of the fingerprint sensor **30** of the present invention provides an effective approach to avoiding spoofing based upon the complex impedance of a finger.

As shown in FIG. **10**, the fingerprint sensor **30** may be considered as including an array of impedance sensing elements **160** for generating signals related to a finger **79** or other object positioned adjacent thereto. In the embodiment described herein, the impedance sensing elements **160** are provided by electric field sensing electrodes **78** and amplifiers **73** (FIG. **2**) associated therewith. In addition, a guard shield **80** may be associated with each electric field sensing electrode **78** and connected to a respective amplifier **73**. Spoof reducing means **161** is provided for determining whether or not an impedance of the object positioned adjacent the array of impedance sensing elements **160** corresponds to a live finger **79** to thereby reduce spoofing of the fingerprint sensor by an object other than a live finger. A spoofing may be indicated, such as by the schematically illustrated lamp **163** and/or used to block further processing. Alternately, a live fingerprint determination may also be indicated by a lamp **164** and/or used to permit further processing of the fingerprint image as will be readily appreciated by those skilled in the art. Many other options for indicating a live fingerprint or an attempted spoofing will be readily appreciated by those skilled in the art.

In one embodiment, the spoof reducing means **161** may include impedance determining means **165** to detect a complex impedance having a phase angle in a range of about 10 to 60 degrees corresponding to a live finger **79**. Alternately, the spoof reducing means **161** may detect an impedance having a phase angle of about 0 degrees corresponding to some objects other than a live finger, such as a sheet of paper having an image thereon, for example. In addition, the spoof reducing means **161** may detect an impedance of 90 degrees corresponding to other objects.

Turning now to FIG. **11**, another embodiment of spoof reducing means is explained. The fingerprint sensor **30** may preferably includes drive means for driving the array of impedance sensing elements **160**, such as the illustrated excitation amplifier **74** (FIG. **2**). The sensor also includes synchronous demodulator means **170** for synchronously demodulating signals from the array of impedance sensing elements **160**. Accordingly, in one particularly advantageous embodiment of the invention, the spoof reducing means comprises means for operating the synchronous demodulator means **170** at at least one predetermined phase rotation angle. For example, the synchronous demodulator means **170** could be operated in a range of about 10 to 60 degrees, and the magnitude compared to a predetermined threshold indicative of a live fingerprint. A live fingerprint typically has a complex impedance within the range of 10 to 60 degrees.

Alternately, ratio generating and comparing means **172** may be provided for cooperating with the synchronous demodulator means **170** for synchronously demodulating signals at first and second phase angles θ_1, θ_2, generating an amplitude ratio thereof, and comparing the amplitude ratio to a predetermined threshold to determine whether the object is a live fingerprint or other object. Accordingly, the synchronous demodulator **170** may be readily used to generate the impedance information desired for reducing spoofing of the sensor **30** by an object other than a live finger. The first angle θ_1 and the second θ_2 may have a difference in a range of about 45 to 90 degrees, for example. Other angles are also contemplated by the invention as would be readily appreciated by those skilled in the art.

The fingerprint sensor **30** also includes an automatic gain control feature to account for a difference in intensity of the

image signals generated by different fingers or under different conditions, and also to account for differences in sensor caused by process variations. It is important for accurately producing a fingerprint image, that the sensor can discriminate between the ridges and valleys of the fingerprint. Accordingly, the sensor **30** includes a gain control feature, a first embodiment of which is understood with reference to FIG. **12**.

As shown in FIG. **12**, the illustrated portion of the fingerprint sensor **30** includes an array of fingerprint sensing elements in the form of the electric field sensing electrodes **78** and surrounding shield electrodes **80** connected to the amplifiers **73**. Other fingerprint sensing elements may also benefit from the following automatic gain control implementations as will be appreciated by those skilled in the art.

The signal processing circuitry of the sensor **30** preferably includes a plurality of analog-to-digital (A/D) converters **180** as illustrated. Moreover, each of these A/D converters **180** may have a controllable scale. Scanning means **182** sequentially connects different elements to the bank of A/D converters **180**. The illustrated gain processor **185** provides range determining and setting means for controlling the range of the A/D converters **180** based upon prior A/D conversions to thereby provide enhanced conversion resolution. The A/D converters **180** may comprise the illustrated reference voltage input V_{ref} and offset voltage input V_{offset} for permitting setting of the range as would be readily appreciated by those skilled in the at. Accordingly, the range determining and setting means may also comprise a first digital-to-analog D/A converter **186** connected between the gain processor **185** and the reference voltage V_{ref} inputs of the A/D converters **180** as would also be readily understood by those skilled in the art. In addition, a second D/A converter **189** is also illustratively connected to the offset voltage inputs V_{offset} from the gain processor **185**.

The gain processor **185** may comprise histogram generating means for generating a histogram, as described above, and based upon prior A/D conversions. The graph adjacent the gain processor **185** in FIG. **12** illustrates a typical histogram plot **191**. The histogram plot **191** includes two peaks corresponding to the sensed ridges and valleys of the fingerprint as would be readily appreciated by those skilled in the art. By setting the range for the A/D converters **180**, the peaks can be readily positioned as desired to thereby account for the variations discussed above and use the full resolution of the A/D converters **180**.

Turning additionally to FIG. **13**, the A/D converters **180** may include an associated input amplifier for permitting setting of the range. In this variation, the range determining and setting means may also comprise the illustrated gain processor **185**, and wherein the amplifier is a programmable gain amplifier (PGA) **187** connected to the processor. A digital word output from the gain processor **185** sets the gain of the PGA **187** so that full use of the resolution of the A/D converters **180** is obtained for best accuracy. A second digital word output from the gain processor **185** and coupled to the amplifier **187** through the illustrated D/A converter **192** may also control the offset of the amplifier as would also be readily appreciated by those skilled in the art.

The range determining and setting means of the gain processor **185** may comprise default setting means for setting a default range for initial ones of the fingerprint sensing elements. The automatic gain control feature of the present invention allows the D/A converters **180** to operate over their full resolution range to thereby increase the accuracy of the image signal processing.

Other aspects, advantages, and features relating to sensing of fingerprints are disclosed in copending U.S. patent application Ser. No. 08/592,469 entitled "Electric Field Fingerprint Sensor and Related Methods", and U.S. patent application Ser. No. 08/671,430 entitled "Integrated Circuit Device Having an Opening Exposing the Integrated Circuit Die and Related Methods", both assigned to the assignee of the present invention, and the entire disclosures of which are incorporated herein by reference. In addition, many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

That which is claimed is:

1. A fingerprint sensor comprising:

a substrate;

a plurality of semiconductor devices on said substrate and defining active circuit portions;

a first metal layer on said substrate interconnecting predetermined ones of said plurality of semiconductor devices;

a first dielectric layer on said first metal layer;

a second metal layer on said first dielectric layer defining a ground plane;

a second dielectric layer on said second metal layer; and

a third metal layer on said second dielectric layer and comprising an array of electric field sensing electrodes connected to active circuit portions for generating signals related to a sensed fingerprint.

2. A fingerprint sensor according to claim **1** further comprising a third dielectric layer on said third metal layer.

3. A fingerprint sensor according to claim **1** further comprising a package surrounding said substrate and having an opening aligned with the array of electric field sensing electrodes.

4. A fingerprint sensor according to claim **3** further comprising a first external electrode carried by said package for contact by a finger.

5. A fingerprint sensor according to claim **4** further comprising excitation drive means connected between the ground plane and said first external electrode for generating electric fields between the electric field sensing electrodes and adjacent finger portions.

6. A fingerprint sensor according to claim **4** further comprising power control means for controlling operation of active circuit portions based upon sensing finger contact with said first external electrode.

7. A fingerprint sensor according to claim **6** wherein said power control means comprises wake-up means for only powering active circuit portions upon sensing finger contact with said first external electrode to thereby conserve power.

8. A fingerprint sensor according to claim **6** wherein said power control means further comprises protection means for grounding active circuit portions upon not sensing finger contact with said first external electrode.

9. A fingerprint sensor according to claim **3** further comprising finger charge bleed means for bleeding a charge from a finger upon contact therewith.

10. A fingerprint sensor according to claim **9** wherein said finger charge bleed means comprises:

a second external electrode carried by said package for contact by a finger;

a charge bleed resistor connected between said second external electrode and an earth ground.

11. A fingerprint sensor according to claim **10** wherein said second external electrode comprises an electrically conductive movable cover for the opening in said package.

12. A fingerprint sensor according to claim **1** further comprising:

a shield electrode adjacent each electric field sensing electrode; and

an amplifier having an input connected to each electric field sensing electrode, and having an output connected to each respective shield electrode, said amplifier having an amplification gain greater than about one to thereby increase noise rejection.

13. A fingerprint sensor comprising:

a substrate;

a plurality of semiconductor devices adjacent said substrate and defining active circuit portions for generating an output related to a sensed fingerprint;

a package surrounding said substrate;

a first external electrode carried by said package for contact by a finger; and

power control means for controlling operation of active circuit portions based upon sensing finger contact with said first external electrode.

14. A fingerprint sensor according to claim **13** further comprising at least one conductive layer comprising an array of electric field sensing electrodes connected to active circuit portions.

15. A fingerprint sensor according to claim **14** further comprising excitation drive means connected to said first external electrode for generating electric fields between the electric field sensing electrodes and adjacent finger portions.

16. A fingerprint sensor according to claim **13** wherein said power control means comprises wake-up means for only powering active circuit portions upon sensing finger contact with said first external electrode to thereby conserve power.

17. A fingerprint sensor according to claim **13** wherein said power control means further comprises protection means for grounding active circuit portions upon not sensing finger contact with said first external electrode.

18. A fingerprint sensor according to claim **17** further comprising finger charge bleed means for bleeding a charge from a finger upon contact therewith, and wherein said finger charge bleed means and said protection means cooperate so that active circuit portions remain grounded until said bleed means bleeds the charge from the finger.

19. A fingerprint sensor according to claim **18** wherein said finger charge bleed means comprises:

a second external electrode carried by said package for contact by a finger; and

a charge bleed resistor connected between said second external electrode and an earth ground.

20. A fingerprint sensor according to claim **19** wherein said second external electrode comprises an electrically conductive movable cover for said package.

21. A fingerprint sensor according to claim **19** wherein said at least one conductive layer comprises a ground plane layer connected to said charge bleed resistor.

22. A fingerprint sensor comprising:

a substrate;

a plurality of semiconductor devices adjacent said substrate and defining active circuit portions for generating an output related to a sensed fingerprint;

a package surrounding said substrate;

finger charge bleed means for bleeding a charge from a finger upon contact therewith to protect the active circuit portions, said finger charge bleed means comprising a second external electrode carried by said package for contact by a finger and a charge bleed resistor connected between said second external electrode and an earth ground.

23. A fingerprint sensor according to claim **22** wherein said second external electrode comprises an electrically conductive movable cover for said package.

24. A fingerprint sensor according to claim **22** further comprising at least one conductive layer comprising an array of electric field sensing electrodes connected to the active circuit portions.

25. A fingerprint sensor according to claim **24** further comprising:

a first external electrode carried by said package; and

excitation drive means connected to said first external electrode for generating electric fields between the electric field sensing electrodes and adjacent finger portions.

26. A fingerprint sensor comprising:

a substrate;

at least one electrically conductive layer adjacent said substrate and comprising portions defining an array of pairs of electric field sensing electrodes and associated shield electrodes; and

a respective amplifier connected between each pair of electric field sensing electrodes and associated shield electrodes, each amplifier having an amplification gain greater than about one to thereby increase noise rejection.

27. A fingerprint sensor according to claim **26** wherein each amplifier has an input connected to each electric field sensing electrode and has an output connected to each respective shield electrode.

28. A fingerprint sensor according to claim **26** further comprising a plurality of semiconductor devices adjacent said substrate and defining the amplifiers.

29. A method for making a fingerprint sensor comprising the steps of:

forming a plurality of semiconductor devices on a substrate and defining active circuit portions;

forming a first metal layer on the substrate interconnecting predetermined ones of the plurality of semiconductor devices;

forming a first dielectric layer on the first metal layer;

forming a second metal layer on the first dielectric layer defining a ground plane;

forming a second dielectric layer on the second metal layer; and

forming a third metal layer on the second dielectric layer and comprising an array of electric field sensing electrodes connected to active circuit portions for generating signals related to a sensed fingerprint.

30. A method according to claim **29** further comprising the step of forming a third dielectric layer on the third metal layer.

31. A method according to claim **29** further comprising the step of forming a package surrounding the substrate and having an opening aligned with the array of electric field sensing electrodes.

32. A method according to claim **31** further comprising the step of forming a first external electrode carried by the package for contact by a finger.

33. A method according to claim **31** further comprising the steps of:

forming a second external electrode carried by the package for contact by a finger; and

connecting a charge bleed resistor between the second external electrode and an earth ground.

34. A method for controlling operation of a fingerprint sensor of a type comprising a plurality of semiconductor devices on a substrate and defining active circuit portions for generating an output related to a sensed fingerprint, a package surrounding the substrate, a first external electrode carried by the package for contact by a finger, and power control means positioned on the substrate and connected to the active circuit portions, the method comprising the steps of:

only powering active circuit portions upon sensing finger contact with the first external electrode to thereby conserve power; and

grounding active circuit portions upon not sensing finger contact with the first external electrode.

35. A method according to claim **34** further comprising the step of bleeding a charge from the finger upon initial contact of the finger with the fingerprint package and before switching from grounding of the active circuit portions to powering same.

36. A method of increasing noise rejection in a fingerprint sensor of a type comprising a substrate, and at least one electrically conductive layer adjacent said substrate and comprising portions defining an array of electric field sensing electrodes, the method comprising the steps of:

forming a shield electrode for each respective electric field sensing electrode;

forming a respective amplifier connected between each pair of electric field sensing electrodes and associated shield electrodes; and

operating each amplifier at an amplification gain greater than about one to thereby increase noise rejection.

* * * * *

EXHIBIT D

US005963679A

United States Patent [19]

Setlak

[11] **Patent Number: 5,963,679**

[45] **Date of Patent: *Oct. 5, 1999**

[54] **ELECTRIC FIELD FINGERPRINT SENSOR APPARATUS AND RELATED METHODS**

[75] Inventor: **Dale R. Setlak**, Melbourne, Fla.

[73] Assignee: **Harris Corporation**, Melbourne, Fla.

[*] Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

[21] Appl. No.: **08/592,469**

[22] Filed: **Jan. 26, 1996**

[51] **Int. Cl.**[6] **G06K 7/00**; G06K 9/00

[52] **U.S. Cl.** **382/312**; 382/124; 382/115

[58] **Field of Search** 382/312, 324, 382/124–127, 321, 115, 223, 274, 261, 270, 275, 205, 211; 283/78; 73/862.046

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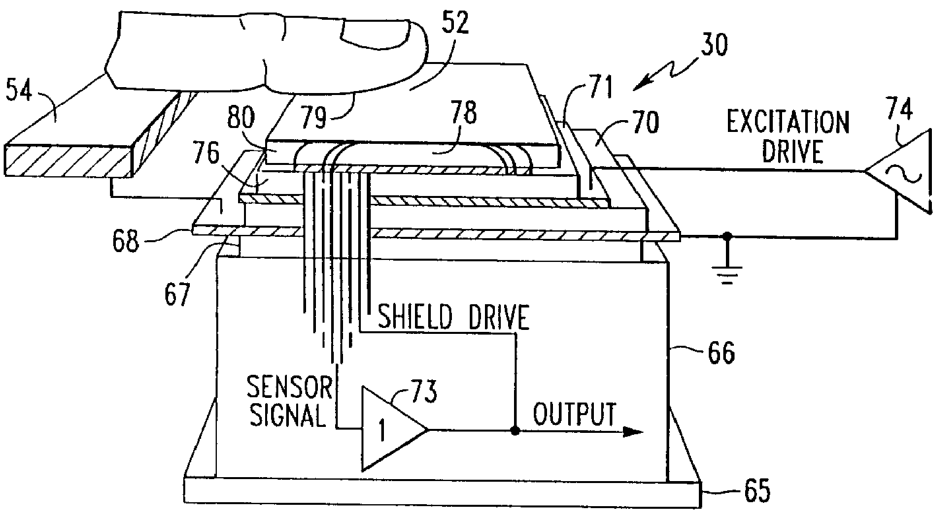
Primary Examiner—Thomas D. Lee
Assistant Examiner—Wenpeng Chen
Attorney, Agent, or Firm—Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A. Attorneys at Law

[57] **ABSTRACT**

A fingerprint sensor includes an array of electric field sensing electrodes, a dielectric layer on the sensing electrodes with the dielectric layer for receiving a finger adjacent thereto, and a driver for applying an electric field drive signal to the sensing electrodes and adjacent portions of the finger so that the sensing electrodes produce a fingerprint image output signal. In one embodiment of the invention, the driver provides a coherent drive signal for the array. A respective shield electrode may be associated with each of the electric field sensing electrodes for shielding each electric field sensing electrode from adjacent sensing electrodes. Each shield electrode may be actively driven for further shielding. The fingerprint sensor preferably further includes a synchronous demodulator and contrast enhancer for more accurate output image signals. The fingerprint sensor may be effectively used to control access to a computer workstation. Method aspects are also disclosed.

51 Claims, 10 Drawing Sheets



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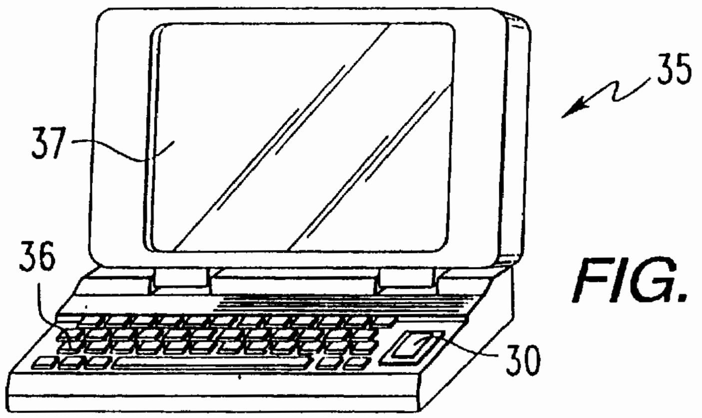

FIG. 1

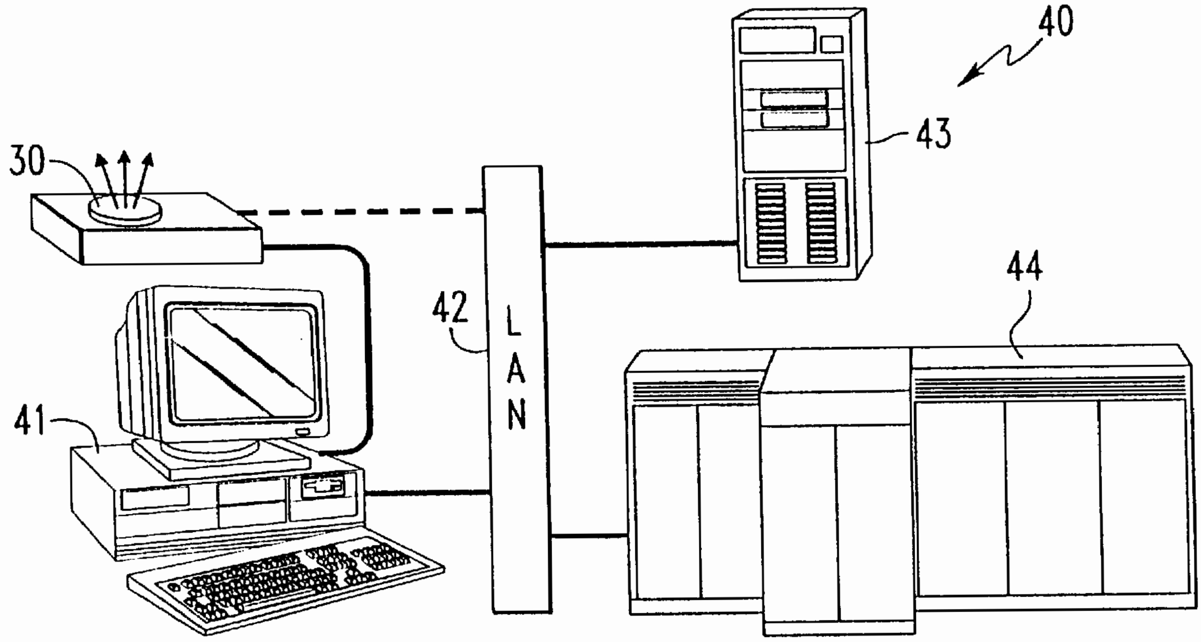

FIG. 2

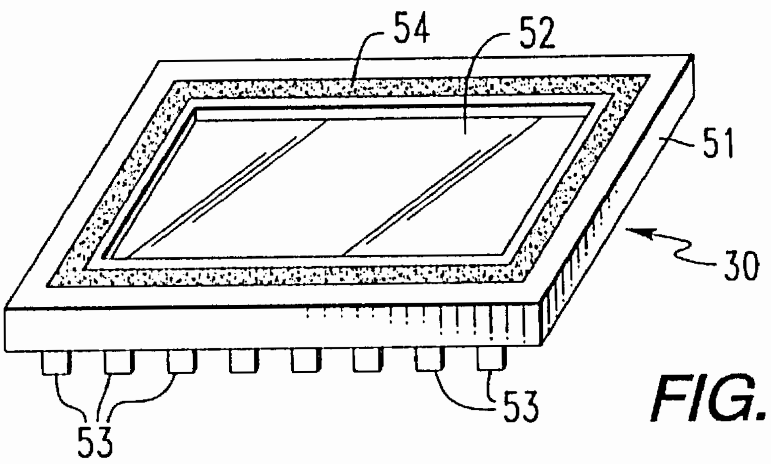

FIG. 3

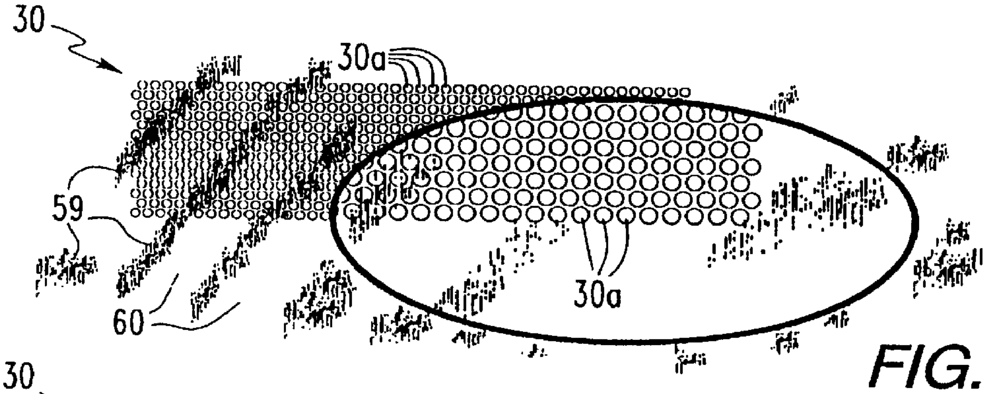

FIG. 4

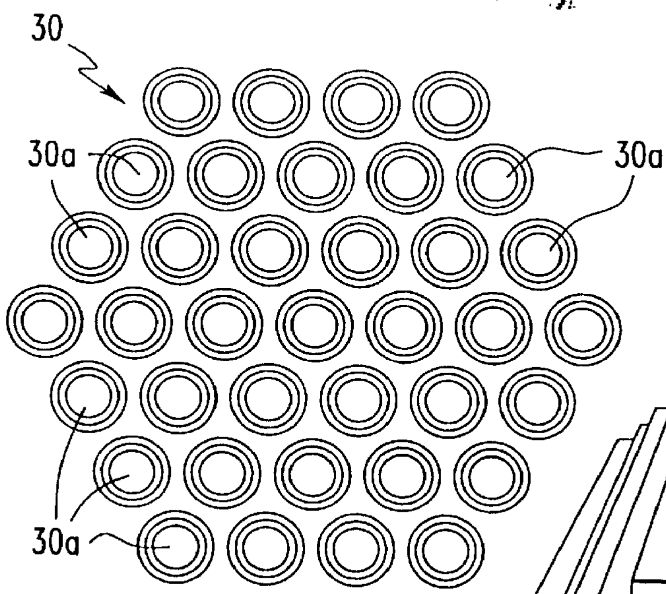

FIG. 5

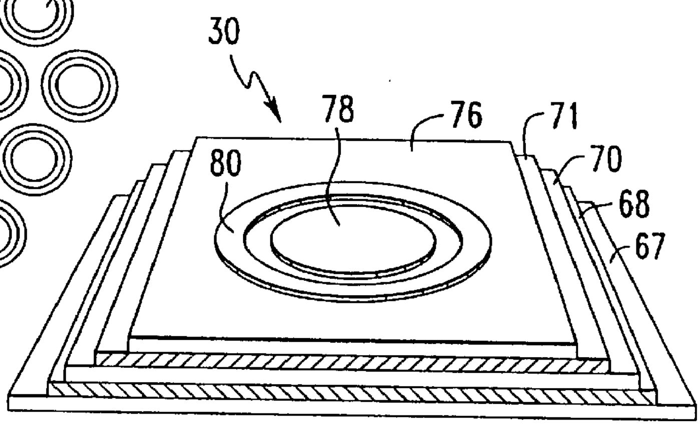

FIG. 6

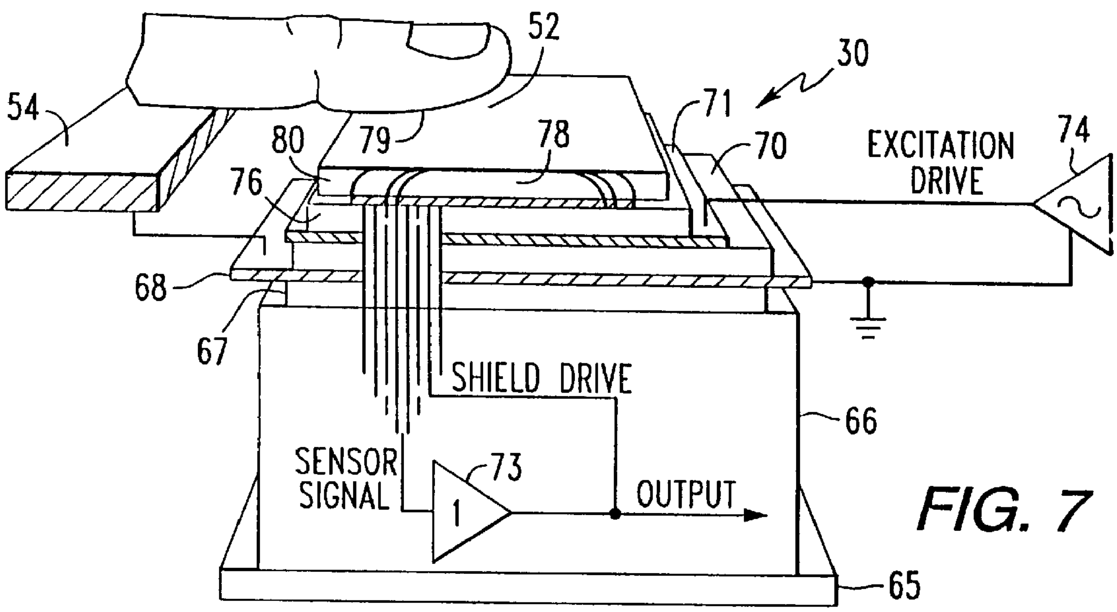

FIG. 7

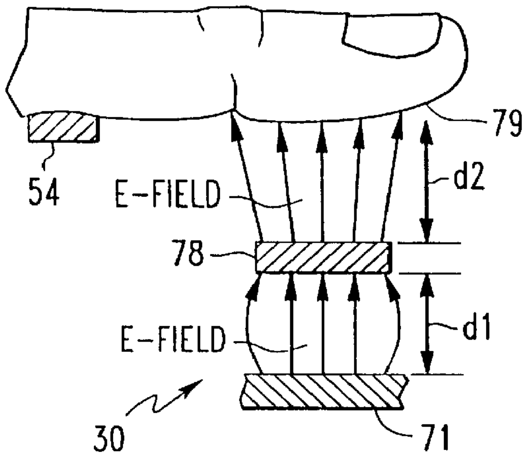

FIG. 8

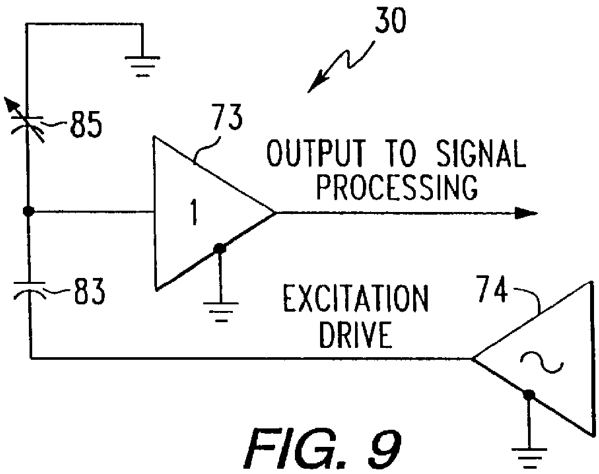

FIG. 9

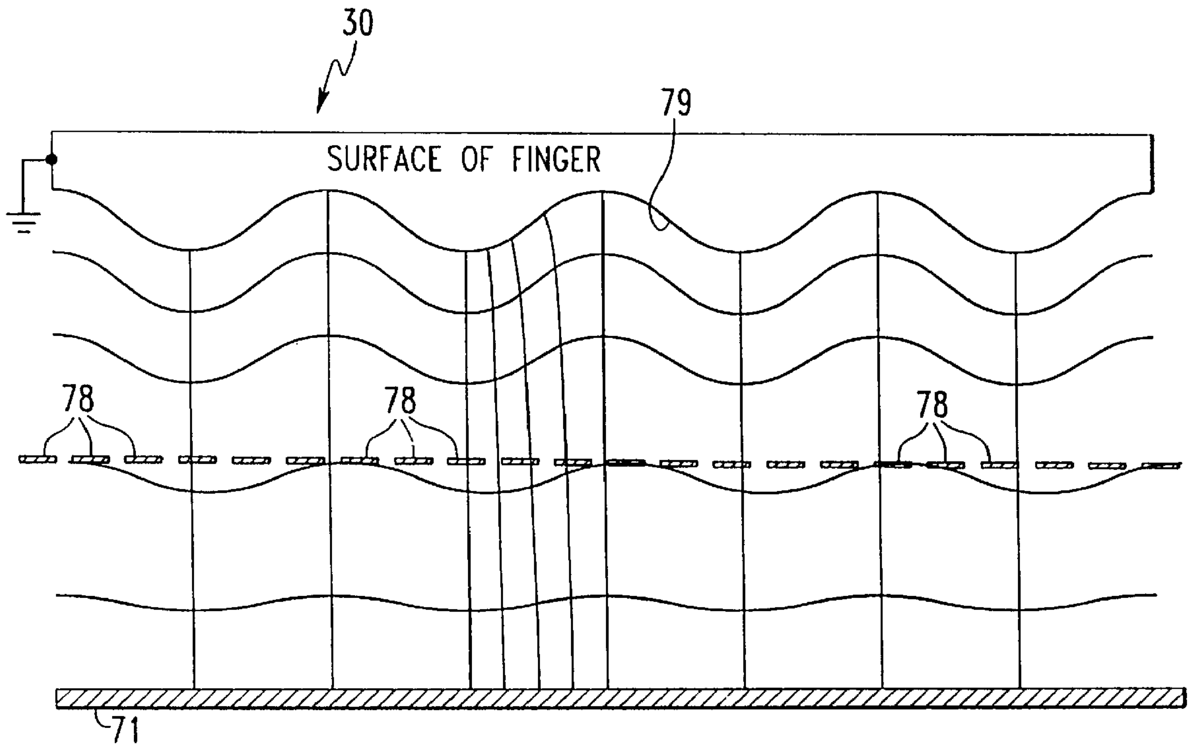

FIG. 10

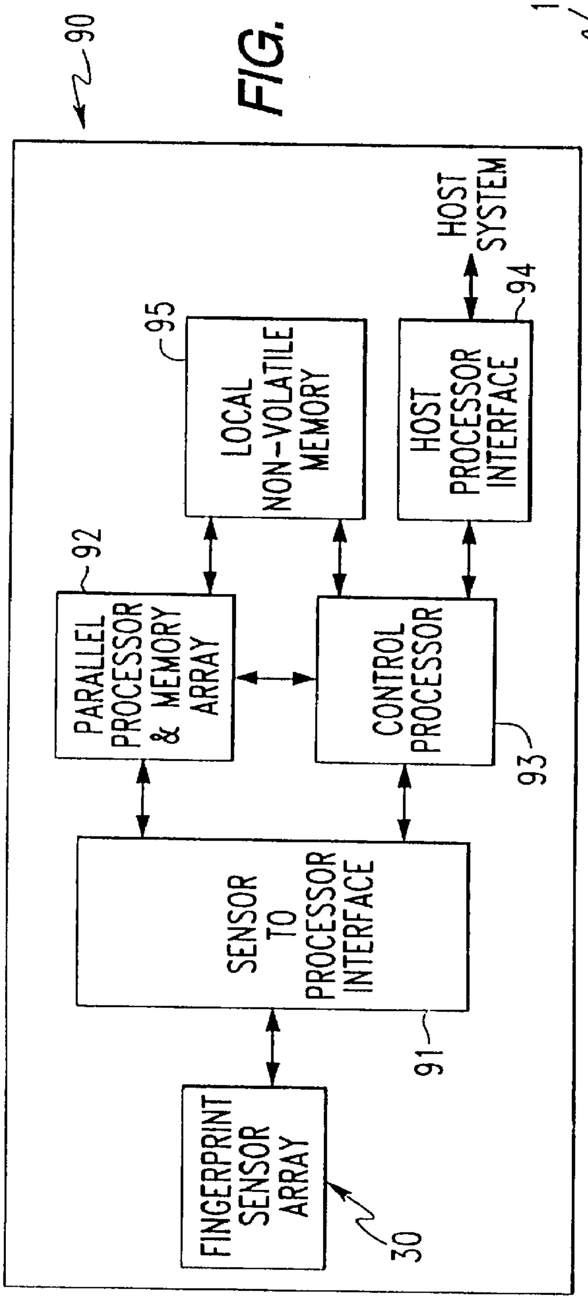
90
FINGERPRINT SENSOR ARRAY
30
SENSOR TO PROCESSOR INTERFACE
91
PARALLEL PROCESSOR & MEMORY ARRAY
92
CONTROL PROCESSOR
93
LOCAL NON-VOLATILE MEMORY
95
HOST PROCESSOR INTERFACE
94
HOST SYSTEM

FIG. 11

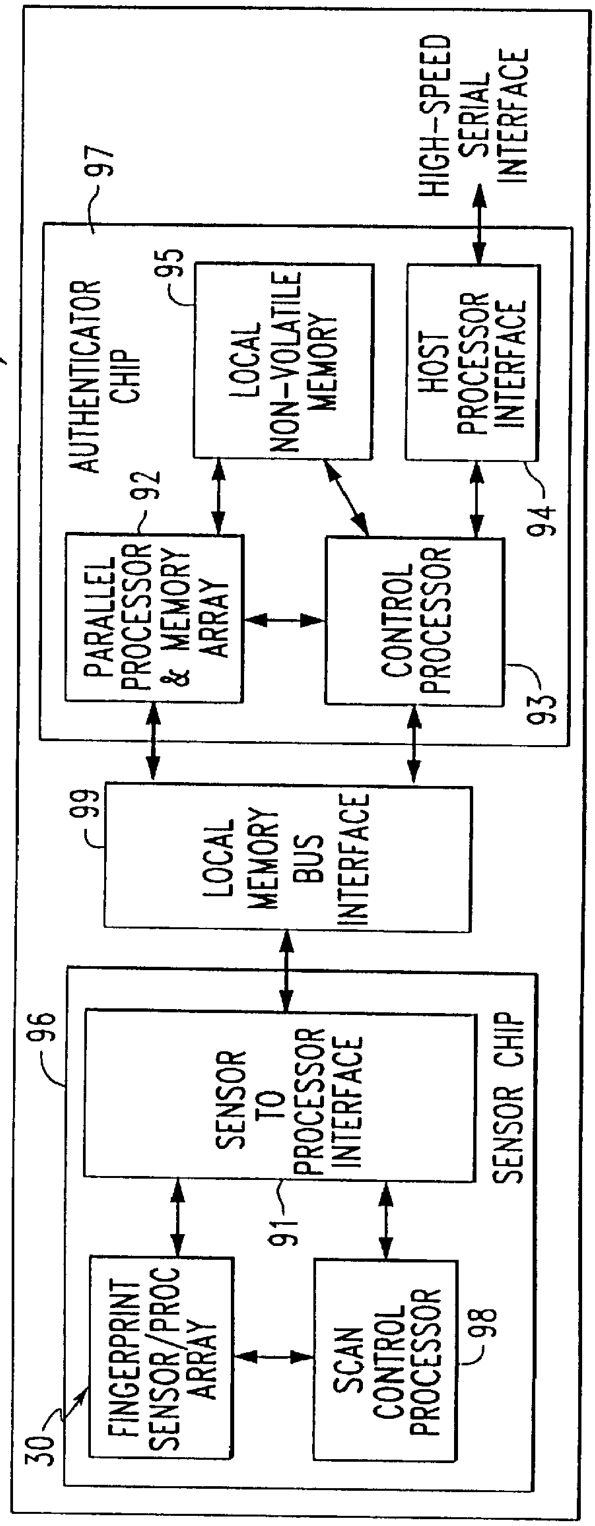
100
SENSOR CHIP
96
FINGERPRINT SENSOR/PROC ARRAY
30
SCAN CONTROL PROCESSOR
98
SENSOR TO PROCESSOR INTERFACE
91
LOCAL MEMORY BUS INTERFACE
99
AUTHENTICATOR CHIP
97
PARALLEL PROCESSOR & MEMORY ARRAY
92
CONTROL PROCESSOR
93
LOCAL NON-VOLATILE MEMORY
95
HOST PROCESSOR INTERFACE
94
HIGH-SPEED SERIAL INTERFACE

FIG. 12

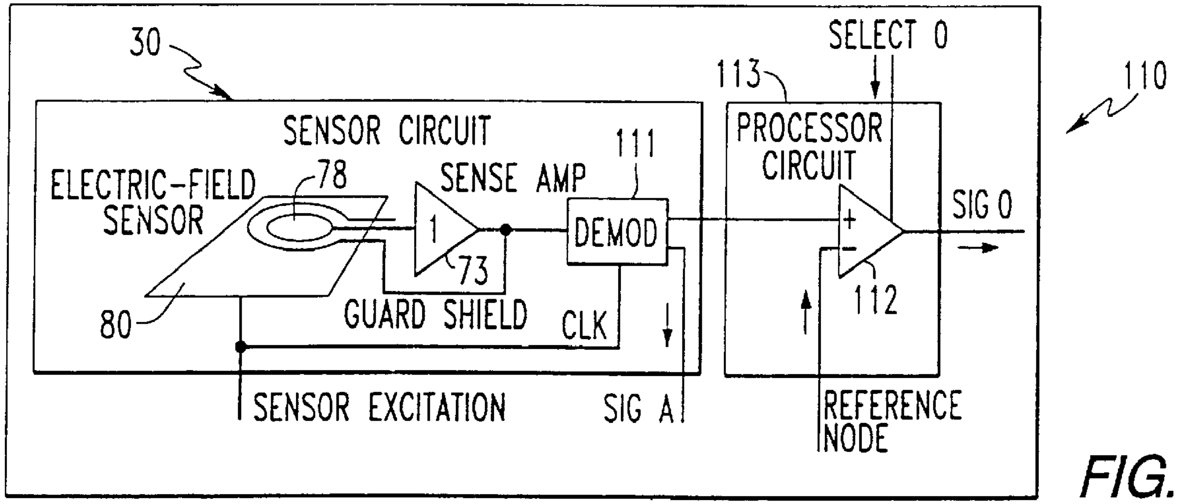
30
110
SELECT 0
113
SENSOR CIRCUIT
111
PROCESSOR CIRCUIT
ELECTRIC-FIELD SENSOR
78
SENSE AMP
DEMOD
1
+
−
SIG 0
73
112
80
GUARD SHIELD
CLK
SENSOR EXCITATION
SIG A
REFERENCE NODE

FIG. 13

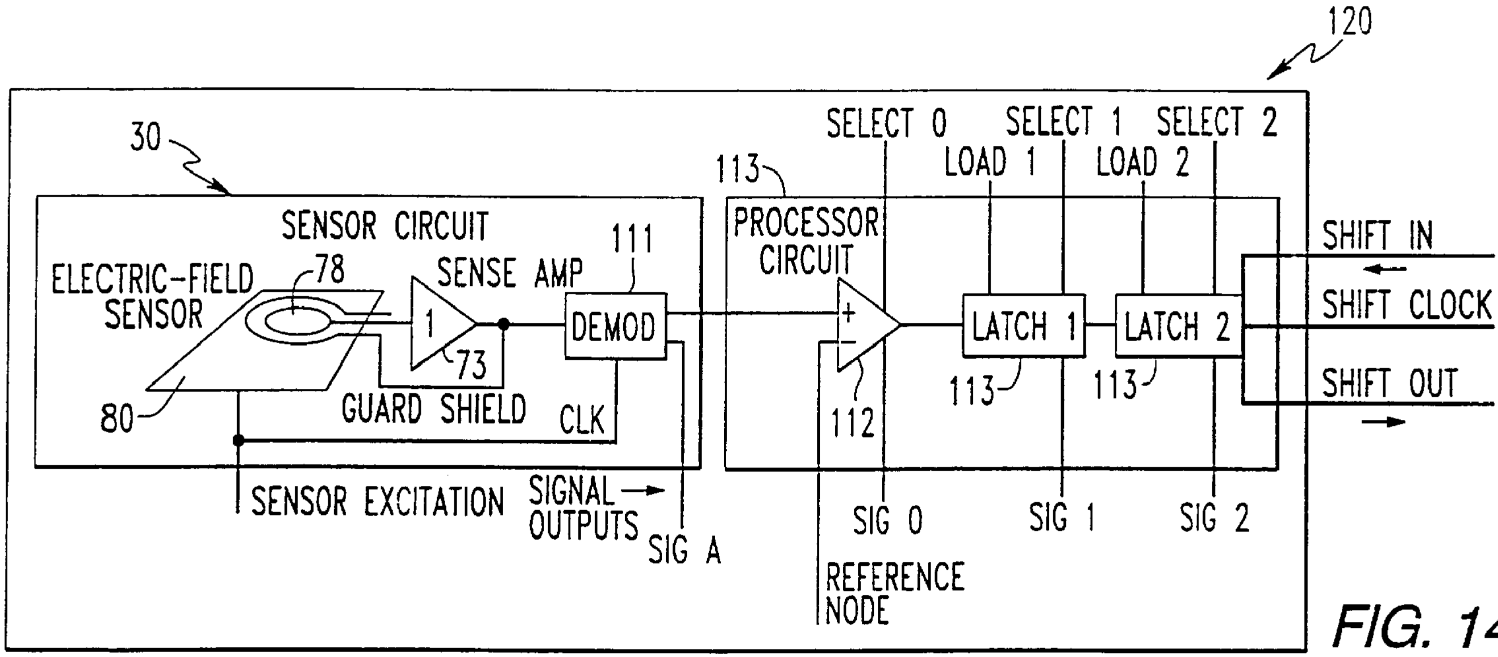
120
30
SELECT 0
SELECT 1
SELECT 2
113
LOAD 1
LOAD 2
SENSOR CIRCUIT
111
PROCESSOR CIRCUIT
ELECTRIC-FIELD SENSOR
78
SENSE AMP
SHIFT IN
DEMOD
LATCH 1
LATCH 2
SHIFT CLOCK
1
+
−
73
113
113
SHIFT OUT
80
GUARD SHIELD
CLK
112
SENSOR EXCITATION
SIGNAL OUTPUTS
SIG A
SIG 0
SIG 1
SIG 2
REFERENCE NODE

FIG. 14

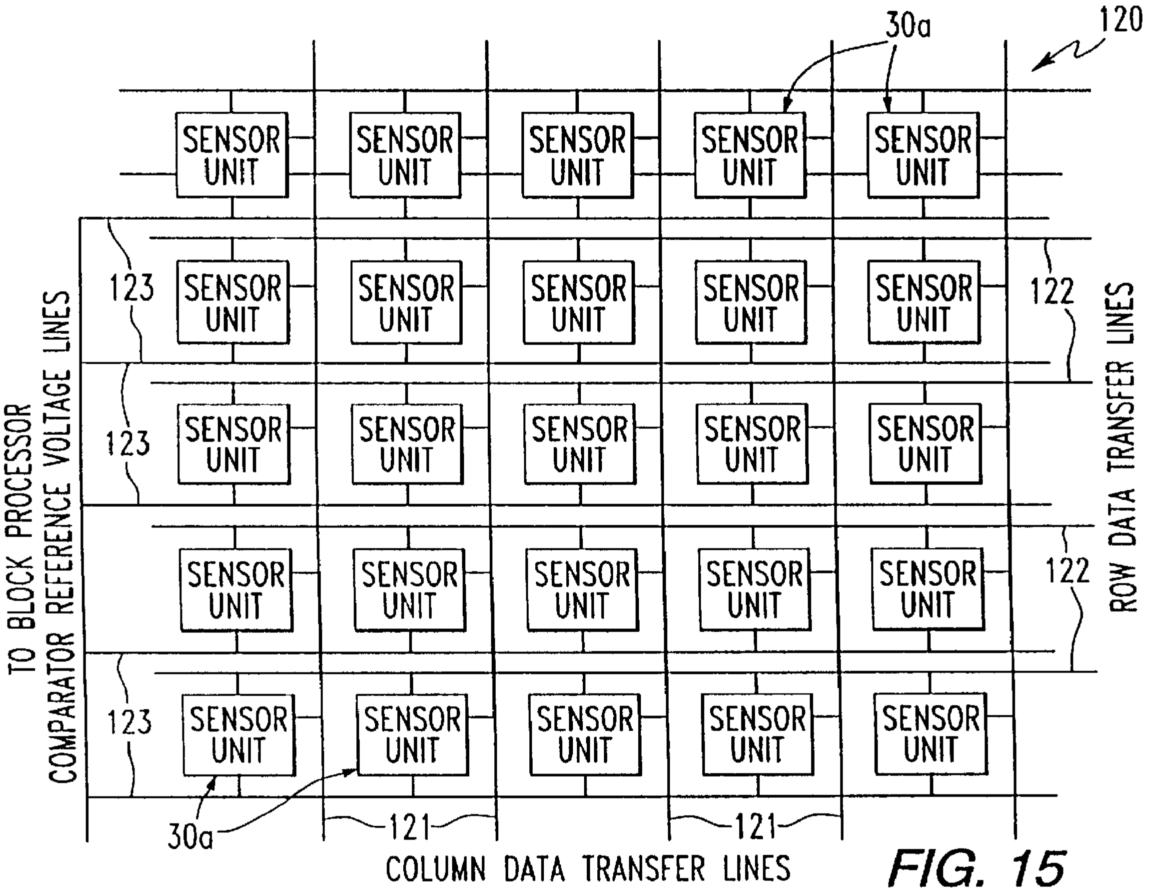
30a
120
SENSOR UNIT
123
122
TO BLOCK PROCESSOR
COMPARATOR REFERENCE VOLTAGE LINES
ROW DATA TRANSFER LINES
121
COLUMN DATA TRANSFER LINES

FIG. 15

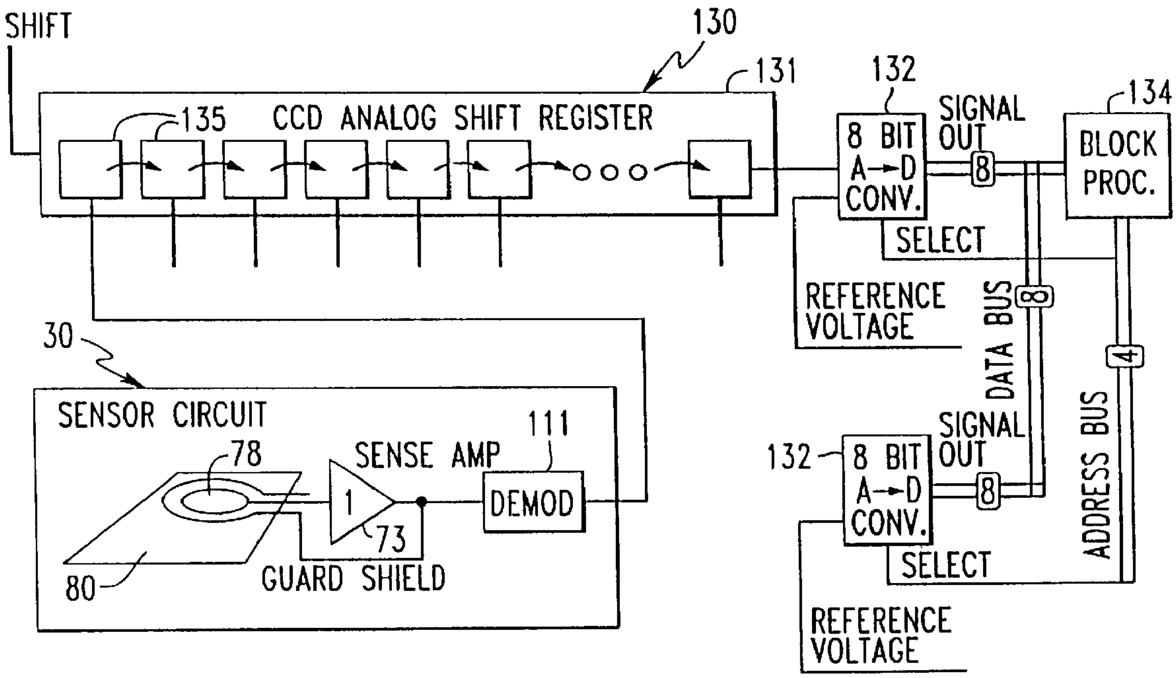
SHIFT
130
131
132
135
CCD ANALOG SHIFT REGISTER
8 BIT A→D CONV.
SIGNAL OUT
8
134
BLOCK PROC.
SELECT
REFERENCE VOLTAGE
DATA BUS
4
ADDRESS BUS
30
SENSOR CIRCUIT
78
SENSE AMP
111
1
DEMOD
73
80
GUARD SHIELD

FIG. 16

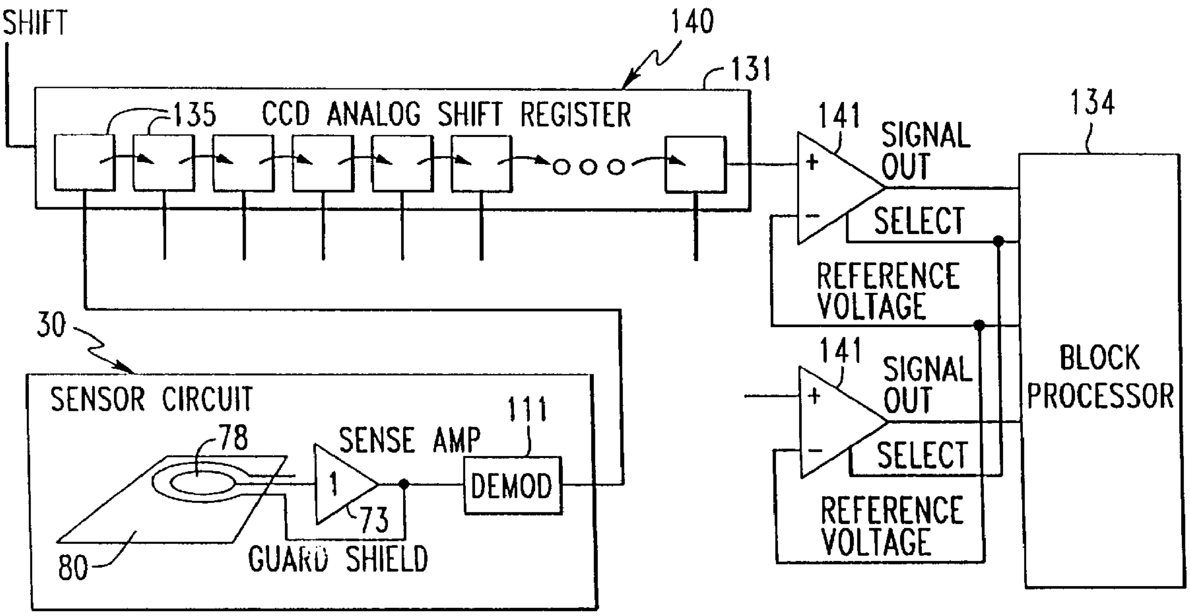
SHIFT
140
131
135
CCD ANALOG SHIFT REGISTER
141
SIGNAL OUT
SELECT
REFERENCE VOLTAGE
134
BLOCK PROCESSOR
30
SENSOR CIRCUIT
78
SENSE AMP
111
DEMOD
73
80
GUARD SHIELD

FIG. 17

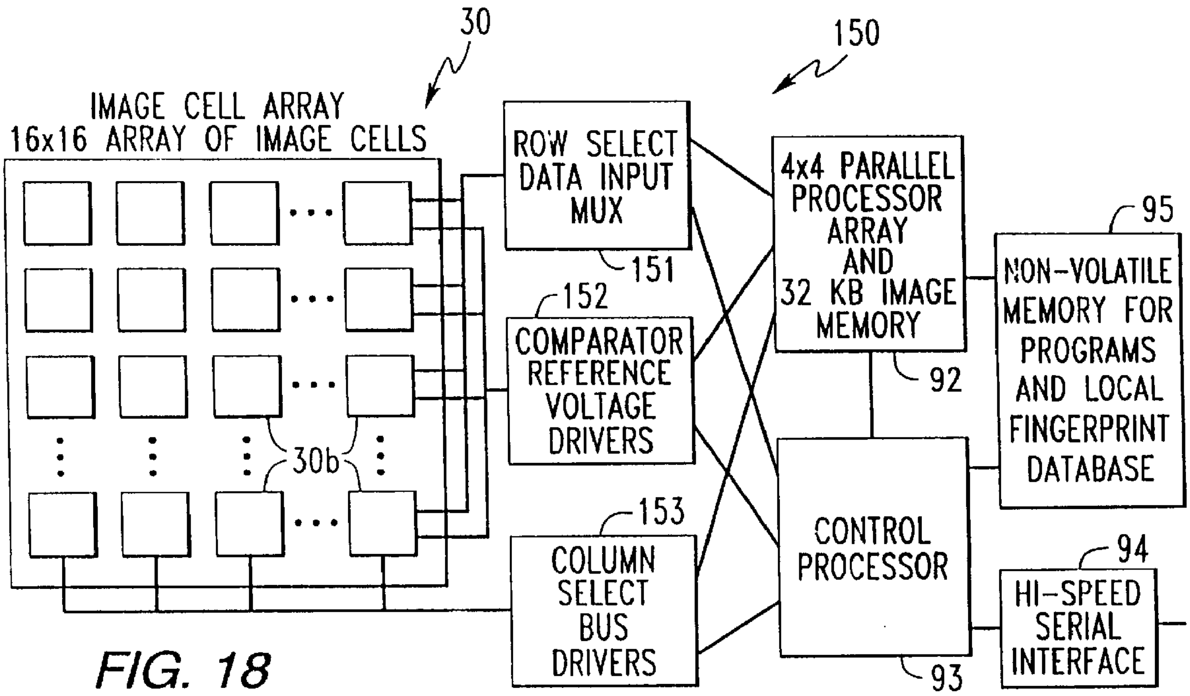
30
IMAGE CELL ARRAY
16x16 ARRAY OF IMAGE CELLS
30b
ROW SELECT DATA INPUT MUX
151
152
COMPARATOR REFERENCE VOLTAGE DRIVERS
153
COLUMN SELECT BUS DRIVERS
150
4x4 PARALLEL PROCESSOR ARRAY AND 32 KB IMAGE MEMORY
92
CONTROL PROCESSOR
93
95
NON-VOLATILE MEMORY FOR PROGRAMS AND LOCAL FINGERPRINT DATABASE
94
HI-SPEED SERIAL INTERFACE

FIG. 18

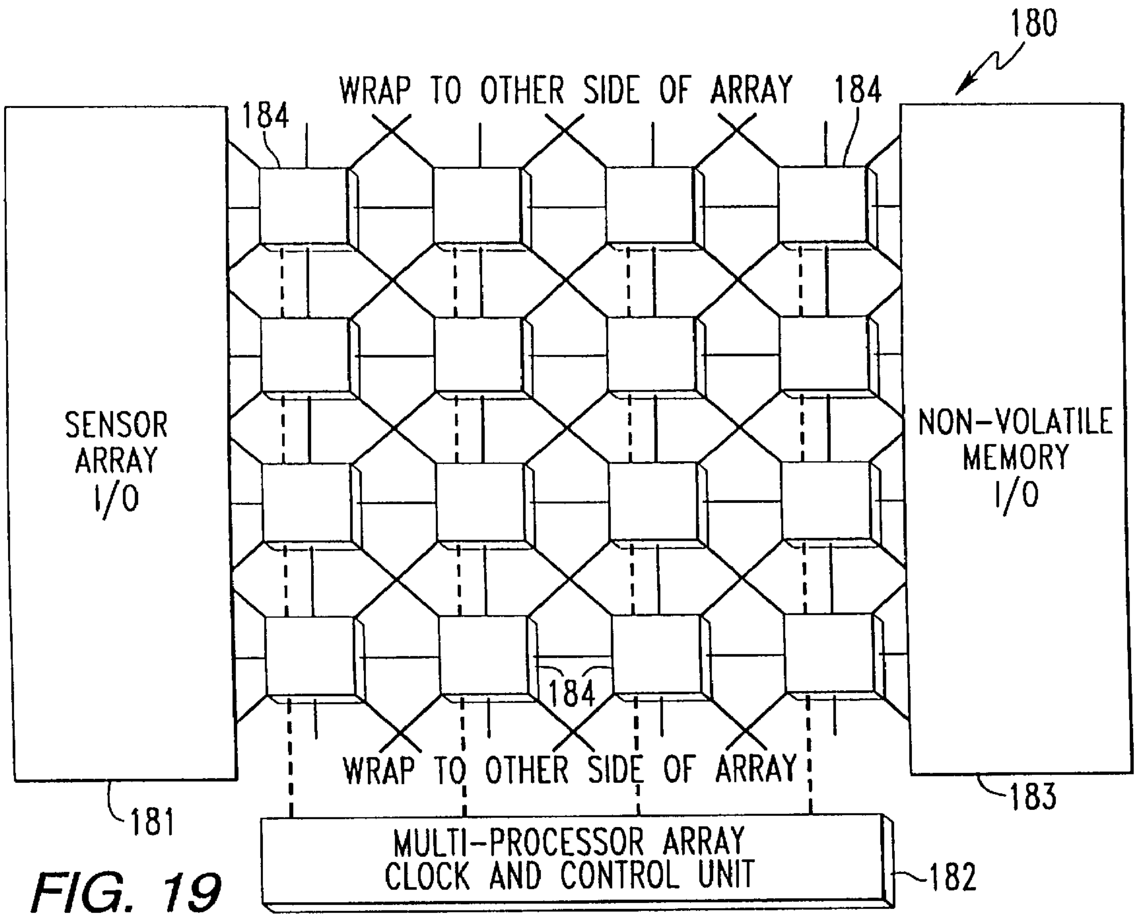
180
WRAP TO OTHER SIDE OF ARRAY
184
184
SENSOR ARRAY I/O
NON-VOLATILE MEMORY I/O
184
WRAP TO OTHER SIDE OF ARRAY
181
183
MULTI-PROCESSOR ARRAY CLOCK AND CONTROL UNIT
182

FIG. 19

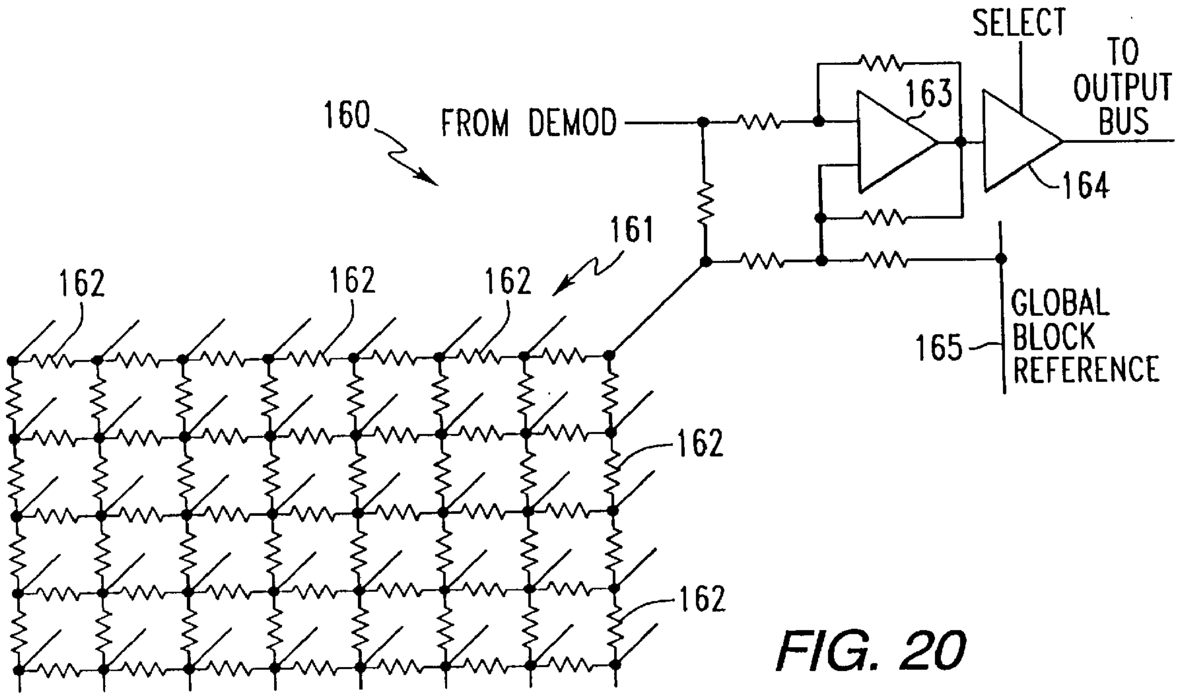
SELECT
TO OUTPUT BUS
163
160
FROM DEMOD
164
161
162
162
162
GLOBAL BLOCK REFERENCE
165
162
162

FIG. 20

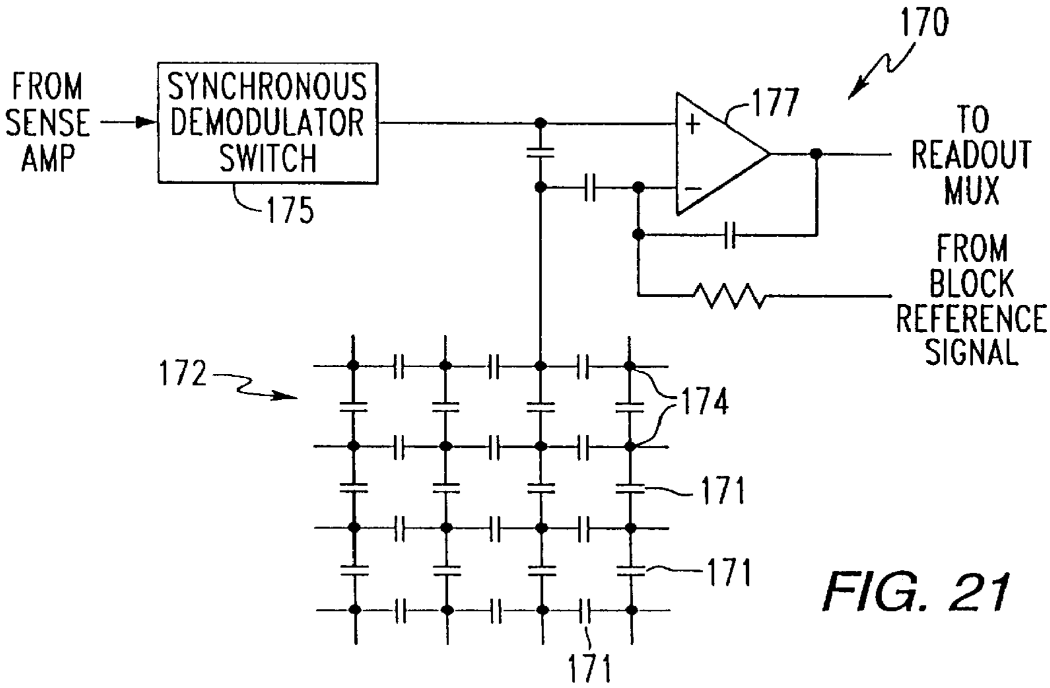

FIG. 21

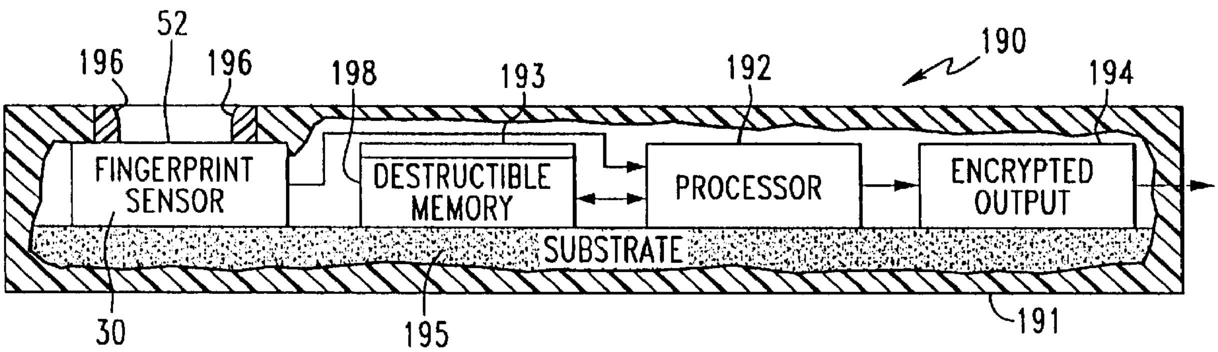

FIG. 22

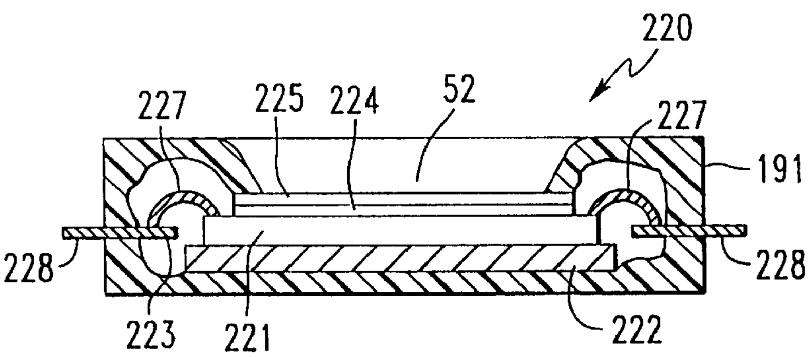

FIG. 23

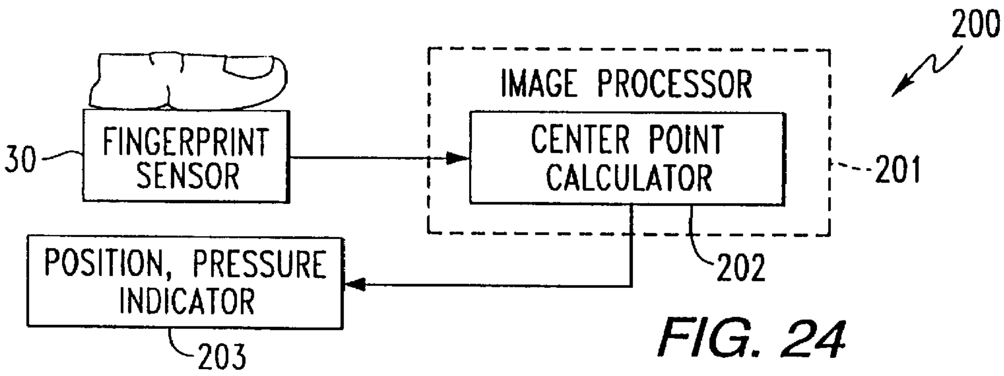

FIG. 24

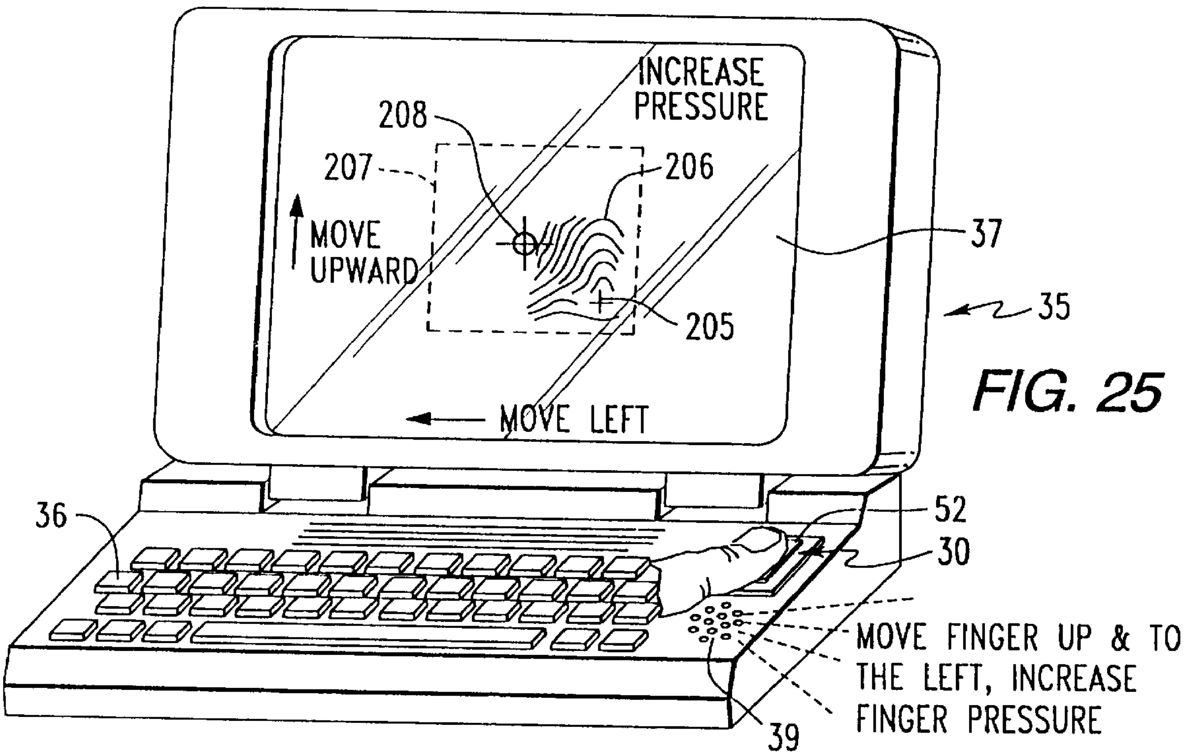

FIG. 25

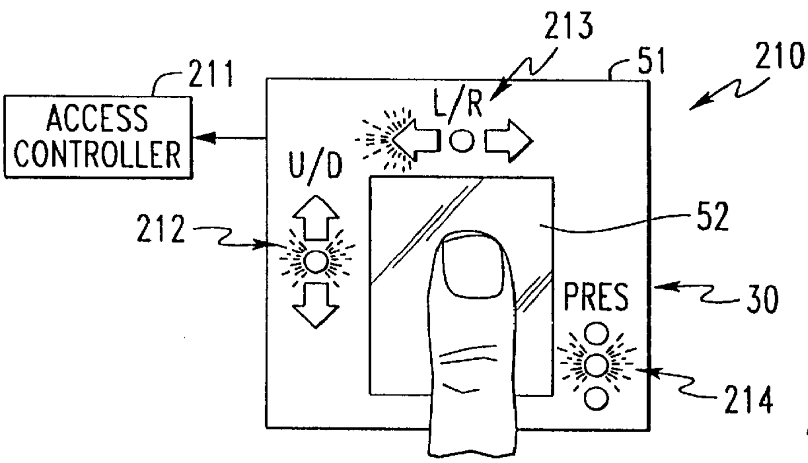

FIG. 26

ELECTRIC FIELD FINGERPRINT SENSOR APPARATUS AND RELATED METHODS

FIELD OF THE INVENTION

The present invention relates to the field of personal identification and verification, and, more particularly, to the field of fingerprint sensing and processing.

BACKGROUND OF THE INVENTION

Fingerprint sensing and matching is a reliable and widely used technique for personal identification or verification. In particular, a common approach to fingerprint identification involves scanning a sample fingerprint or an image thereof and storing the image and/or unique characteristics of the fingerprint image. The characteristics of a sample fingerprint may be compared to information for reference fingerprints already in storage to determine proper identification of a person, such as for verification purposes.

A typical electronic fingerprint sensor is based upon illuminating the finger surface using visible light, infrared light, or ultrasonic radiation. The reflected energy is captured with some form of camera, for example, and the resulting image is framed, digitized and stored as a static digital image. For example, U.S. Pat. No. 4,210,899 to Swonger et al. discloses an optical scanning fingerprint reader cooperating with a central processing station for a secure access application, such as admitting a person to a location or providing access to a computer terminal. U.S. Pat. No. 4,525,859 to Bowles similarly discloses a video camera for capturing a fingerprint image and uses the minutiae of the fingerprints, that is, the branches and endings of the fingerprint ridges, to determine a match with a database of reference fingerprints.

Unfortunately, optical sensing may be affected by stained fingers or an optical sensor may be deceived by presentation of a photograph or printed image of a fingerprint rather than a true live fingerprint. In addition, optical schemes may require relatively large spacings between the finger contact surface and associated imaging components. Moreover, such sensors typically require precise alignment and complex scanning of optical beams. Accordingly, optical sensors may thus be bulky and be susceptible to shock, vibration and surface contamination. Accordingly, an optical fingerprint sensor may be unreliable in service in addition to being bulky and relatively expensive due to optics and moving parts.

In the event of a failure to form an acceptable image of a fingerprint, U.S. Pat. No. 4,947,443 to Costello, for example, discloses a series of indicator lights which give the user a simple go or no-go indication of the acceptability of the fingerprint scanning among other potential system identification failures. In other words, another shortcoming of conventional fingerprint sensors is that inaccurate positioning of the finger relative to the sensor may reduce the ability of the processor to accurately and quickly determine a match between a sample fingerprint and a plurality of reference fingerprints.

U.S. Pat. No. 4,353,056 to Tsikos discloses another approach to sensing a live fingerprint. In particular, the patent discloses an array of extremely small capacitors located in a plane parallel to the sensing surface of the device. When a finger touches the sensing surface and deforms the surface, a voltage distribution in a series connection of the capacitors may change. The voltages on each of the capacitors is determined by multiplexor techniques. Unfortunately, the resilient materials required for the sensor may suffer from long term reliability problems. In addition, multiplexing techniques for driving and scanning each of the individual capacitors may be relatively slow and cumbersome. Moreover, noise and stray capacitances may adversely affect the plurality of relatively small and closely spaced capacitors.

U.S. Pat. No. 5,325,442 to Knapp discloses a fingerprint sensor including a plurality of sensing electrodes. Active addressing of the sensing electrodes is made possible by the provision of a switching device associated with each sensing electrode. A capacitor is effectively formed by each sensing electrode in combination with the respective overlying portion of the finger surface which, in turn, is at ground potential. The sensor may be fabricated using semiconductor wafer and integrated circuit technology. The dielectric material upon which the finger is placed may be provided by silicon nitride or a polyimide which may be provided as a continuous layer over an array of sensing electrodes. Further conductors may be provided on the surface of the dielectric material remote from the sensing electrodes and extending over regions between the sensing electrodes, for example, as lines or in grid form, which conductors are grounded in order to improve the electrical contact to the finger surface.

Unfortunately, driving the array of closely spaced sensing electrodes as disclosed in the Knapp et al. patent may be difficult since adjacent electrodes may affect one another. Another difficulty with such a sensor may be its ability to distinguish ridges and valleys of a fingerprint when the conductivity of the skin and any contaminants may vary widely from person-to-person and even over a single fingerprint. Yet another difficulty with such a sensor, as with many optical sensors, is that different portions of the fingerprint may require relatively complicated post image collection processing to provide for usable signal levels and contrast to thereby permit accurate determination of the ridges and valleys of the fingerprint.

Yet another shortcoming of conventional fingerprint sensors is that the leads and internal components of a conventional fingerprint sensor, either optical, ultrasonic or capacitive, may be tampered with, such as to send a false acceptance signal to an associated portion of equipment. Accordingly, even if the sensor is accurate and reliable, it may be readily bypassed to gain access or entry to the equipment or area intended to be protected by the fingerprint sensor.

Greater advances in fingerprint sensing and matching for identification and verification are desirable and may prevent unauthorized use of computer workstations, appliances, vehicles, and confidential data. Inexpensive and effective fingerprint identification may also be used at point-of-sale terminals, and ensure further security of credit and debit cards, firearms, and provide a personal electronic signature. Unfortunately, current sensors and their associated circuitry may be too bulky, expensive and unreliable for a great many applications which would otherwise benefit from fingerprint identification and verification technology.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a fingerprint sensor and related methods for accurately sensing a fingerprint, and which sensor is rugged, compact, reliable and relatively inexpensive.

These and other objects, features and advantages according to the invention are provided by a fingerprint sensor comprising an array of electric field sensing electrodes, a dielectric layer on the electric field sensing electrodes with

the dielectric layer for receiving a finger adjacent thereto, and drive means for applying an electric field drive signal to the electric field sensing electrodes and adjacent portions of the finger so that the electric field sensing electrodes produce a fingerprint image output signal. Accordingly, the many shortcomings and disadvantages of prior art optical sensors are thus overcome, as the sensor in accordance with the present invention may be readily made to be rugged, compact, relatively low cost, and accurate.

In one advantageous embodiment of the invention the drive means preferably comprises coherent drive means for driving the array with a coherent signal. More particularly, the coherent drive means may include a drive electrode adjacent the electric field sensing electrodes, a second dielectric layer between the drive electrode and the electric field sensing electrodes, and a drive circuit for powering the drive electrode to generate the coherent electric field drive signal with a predetermined frequency. The sensor also preferably includes a finger electrode positioned adjacent the dielectric layer for contact with the finger.

Another important embodiment and aspect of the invention includes a respective shield electrode associated with each of the electric field sensing electrodes for shielding each electric field sensing electrode from adjacent sensing electrodes. Each shield electrode may be provided by an electrically conductive layer surrounding a respective sensing electrode with a dielectric layer therebetween. To further reduce the driving requirement for each sensing electrode and reduce the undesirable effects of adjacent electrodes, the fingerprint sensor preferably further comprises active shield driving means for actively driving each of the shield electrodes. The active shield driving means may be provided by an amplifier operatively connected to each electric field sensing electrode and each shield electrode for actively driving the shield electrode with a portion of an output signal from the amplifier.

Yet another significant aspect of the invention addresses the difficulty of variation in finger conductivity and contamination. More particularly, the fingerprint sensor preferably further includes synchronous demodulator means operatively connected to the electric field sensing electrodes for synchronously demodulating signals therefrom so that sensitivity to variations in conductivity is reduced.

Still another significant aspect of the present invention relates to image contrast and uniformity enhancement which has typically been attempted via complicated and relatively slow downstream software driven processing of a fingerprint image signal. The present invention advantageously includes dynamic contrast enhancing means operatively connected to the electric field sensing electrodes and within the integrated circuit of the sensor for dynamically enhancing contrast and uniformity of the fingerprint image output signal.

In one embodiment, the dynamic contrast enhancing means may be provided by a capacitor matrix operatively connected to the electric field sensing electrodes, and an alternating current (AC) capacitor matrix drive means for driving the capacitor matrix. In addition, the AC capacitor matrix drive means may be provided, in part, by the synchronous demodulator described above. In an alternate embodiment, the dynamic contrast enhancing means may comprise a resistor array or matrix operatively connected to the electric field sensing electrodes.

The fingerprint sensor may desirably be implemented using semiconductor processing techniques and wherein the upper dielectric layer, upon which the finger is placed, is an

upper exposed portion of the semiconductor chip containing the sensing and drive electrodes, as well as associated active electronic circuitry. In particular, an amplifier may be operatively connected to each electric field sensing electrode, and multiplexing means provided for selectively reading each of the electric field sensing electrodes. The sensor may also preferably include package means in one embodiment for enclosing the substrate, the active semiconductor layer, the electric field sensing electrodes, and the dielectric layer. The package means preferably has an opening therethrough in registry with the dielectric layer.

The fingerprint sensor may be used in many applications. In one preferred application the sensor is used in combination with a computer workstation, such as a fixed workstation or a portable notebook computer. In other words, the computer workstation preferably comprises a housing, a computer processor positioned within the housing, a display operatively connected to the computer processor, a keyboard operatively connected to the computer processor, and fingerprint sensor means mounted within and protected by the housing and operatively connected to the computer processor.

Moreover, the fingerprint sensor may interface with the computer processor so that the electronics associated with the sensor may be simplified and their expense thereby reduced. Thus, the computer processor preferably comprises access control means for permitting operation of the computer workstation only upon determining a match between a fingerprint sensed by the protectively mounted fingerprint sensor and an authorized reference fingerprint. The fingerprint sensor may be the electric field fingerprint sensor described herein or other sensors may be used.

Method related aspects of the invention are also disclosed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of the fingerprint sensor in combination with a notebook computer in accordance with the present invention.

FIG. **2** is a schematic diagram of the fingerprint sensor in combination with a computer workstation and associated information processing computer and local area network (LAN) in accordance with the present invention.

FIG. **3** is a schematic perspective view of an embodiment of a fingerprint sensor in accordance with the invention.

FIG. **4** is a schematic plan view of a portion of the sensor and an overlying fingerprint pattern in accordance with the present invention with a portion thereof greatly enlarged for clarity of illustration.

FIG. **5** is a greatly enlarged plan view of a portion of the fingerprint sensor in accordance with the invention with the upper dielectric layer removed therefrom for clarity of illustration.

FIG. **6** is a schematic perspective view of a portion of the fingerprint sensor in accordance with the present invention.

FIG. **7** is a schematic fragmentary view of a portion of the fingerprint sensor in accordance with the present invention.

FIG. **8** is a schematic side view, partially in section, illustrating the electric fields in accordance with the present invention.

FIG. **9** is a schematic circuit diagram of a portion of the fingerprint sensor in accordance with the present invention.

FIG. **10** is an enlarged schematic side view, partially in section, further illustrating the electric fields in accordance with the present invention.

FIG. **11** is a schematic block diagram of the fingerprint sensor and associated circuitry in one embodiment in accordance with the present invention.

FIG. **12** is a schematic block diagram of the fingerprint sensor and associated circuitry in another embodiment in accordance with the present invention.

FIG. **13** is a schematic block diagram of an embodiment of a sensor circuit in accordance with the present invention.

FIG. **14** is a schematic block diagram of another embodiment of a sensor circuit in accordance with the present invention.

FIG. **15** is a schematic block diagram illustrating a plurality of sensor units in accordance with the present invention.

FIG. **16** is a schematic block diagram of an embodiment of a portion of the signal processing for the fingerprint sensor in accordance with the present invention.

FIG. **17** is a schematic block diagram of another embodiment of a portion of the signal processing for the fingerprint sensor in accordance with the present invention.

FIG. **18** is a schematic block diagram of yet another embodiment of signal processing circuitry for the fingerprint sensor in accordance with the present invention.

FIG. **19** is a schematic circuit diagram of yet another embodiment of a portion of the signal processing for the fingerprint sensor in accordance with the present invention.

FIG. **20** is a schematic circuit diagram of yet another embodiment of a portion of the signal processing for the fingerprint sensor in accordance with the present invention illustrating a resistor matrix for dynamic contrast enhancement.

FIG. **21** is a schematic circuit diagram of yet another embodiment of a portion of the signal processing for the fingerprint sensor in accordance with the present invention illustrating a capacitor matrix implementation for dynamic contrast enhancement.

FIG. **22** is a schematic block diagram of an embodiment of the fingerprint sensor package in accordance with the present invention.

FIG. **23** is a schematic diagram of another embodiment of the fingerprint sensor package in accordance with the present invention.

FIG. **24** is a schematic block diagram of another aspect of the sensor for illustrating near real-time positioning feedback of finger placement in accordance with the invention.

FIG. **25** is a schematic perspective diagram of a computer illustrating near real-time positioning feedback of finger placement in accordance with the present invention.

FIG. **26** is a schematic perspective diagram of a fingerprint sensor including indicators for illustrating near real-time positioning feedback of finger placement in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout. The scaling of various features, particularly fingers and layers in the drawing figures, have been exaggerated for clarity of explanation.

Referring first to FIGS. **1–3**, the fingerprint sensor **30** in accordance with the invention is initially described. The illustrated sensor **30** includes a housing or package **51**, a dielectric layer **52** exposed on an upper surface of the package which provides a placement surface for the finger, and a plurality of signal conductors **53**. A conductive strip or electrode **54** around the periphery of the dielectric layer **52** also provides a contact electrode for the finger as described in greater detail below. The sensor **30** may provide output signals in a range of sophistication levels depending on the level of processing incorporated in the package as also described in greater detail below.

The fingerprint sensor **30** may be used in many different applications as will be readily appreciated by those skilled in the art, such as for personal identification or verification purposes. For example, the sensor **30** may be used to permit access to a computer workstation, such as a notebook computer **35** including a keyboard **36** and associated folding display screen **37** (FIG. **1**). In other words, user access to the information and programs of the notebook computer **35** may only be granted if the desired fingerprint is first sensed as also described in greater detail herein.

Another application of the fingerprint sensor **30** is illustrated with particular reference to FIG. **2**. The sensor **30** may be used to grant or deny access to a fixed workstation **41** for a computer information system **40**. The system may include a plurality of such workstations **41** linked by a local area network (LAN) **43**, which in turn, is linked to a fingerprint identification server **43**, and an overall central computer **44**. Many other applications for the low cost and reliable electric field sensor **30** in accordance with the invention are contemplated by the invention and will be readily appreciated by those skilled in the art.

Referring now additionally to FIGS. **4–10**, the sensor **30** is described in greater detail. The sensor **30** includes a plurality of individual pixels or sensing elements **30***a* arranged in array pattern as shown perhaps best in FIGS. **4** and **5**. As would be readily understood by those skilled in the art, these sensing elements are relatively small so as to be capable of sensing the ridges **59** and intervening valleys **60** of a typical fingerprint (FIG. **4**). As will also be readily appreciated by those skilled in the art, live fingerprint readings as from the electric field sensor **30** in accordance with the present invention may be more reliable than optical sensing, because the conduction of the skin of a finger in a pattern of ridges and valleys is extremely difficult to simulate. In contrast, an optical sensor may be deceived by a readily prepared photograph or other similar image of a fingerprint, for example.

The sensor **30** includes a substrate **65**, and one or more active semiconductive layers **66** thereon. A ground plane electrode layer **68** is above the active layer **66** and separated therefrom by an insulating layer **67**. A drive electrode layer **71** is positioned over another dielectric layer **70** and is connected to an excitation drive amplifier **74**. The excitation drive signal may be typically in the range of about 1 KHz to 1 MHz and is coherently delivered across all of the array. Accordingly, the drive or excitation electronics are thus relatively uncomplicated and the overall cost of the sensor **30** may be reduced, while the reliability is increased.

Another insulating layer **76** is on the drive electrode layer **71**, and an illustratively circularly shaped sensing electrode **78** is on the insulating layer **76**. The sensing electrode **78**

may be connected to sensing electronics **73** formed in the active layer **66** as schematically illustrated, and as would be readily appreciated by those skilled in the art.

An annularly shaped shield electrode **80** surrounds the sensing electrode **78** in spaced relation therefrom. As would be readily appreciated by those skilled in the art the sensing electrode **78** and its surrounding shield electrode **80** may have other shapes, such as hexagonal, for example, to facilitate a close packed arrangement or array of pixels or sensing elements **30***a*. The shield electrode **80** is an active shield which is driven by a portion of the output of the amplifier circuit **73** to help focus the electric field energy and, moreover, to thereby reduce the need to drive adjacent electrodes. Accordingly, the sensor **30** permits all of the sensing elements to be driven by a coherent drive signal in sharp contrast to prior art sensors which required that each sensing electrode be individually driven.

As understood with additional reference to FIGS. **8–10**, the excitation electrode **71** generates a first electric field to the sensing electrode **78** and a second electric field between the sensing electrode **78** and the surface of the finger **79**, over the distances d**1** and d**2**, respectively. In other terms, a first capacitor **83** (FIG. **9**) is defined between the excitation electrode **71** and the sensing electrode **78**, and a second capacitor **85** is defined between the finger skin **79** and ground. The capacitance of the second capacitor **85** varies depending on whether the sensing electrode **78** is adjacent a ridge or valley. Accordingly, the sensor **30** can be modeled as a capacitive voltage divider. The voltage sensed by the unity gain voltage follower or amplifier **73** will change as the distance d**2** changes.

In general, the sensing elements **30***a* operate at very low currents and at very high impedances. For example, the output signal from each sensing electrode **78** is desirably about 5 to 10 millivolts to reduce the effects of noise and permit further processing of the signals. The approximate diameter of each sensing element **30***a* , as defined by the outer dimensions of the shield electrode **80,** may be about 0.002 to 0.005 inches in diameter. The excitation dielectric layer **76** and surface dielectric layer **52** may desirably have a thickness in the range of about 1 μm. The ground plane electrode **68** shields the active electronic devices from the excitation electrode **71**. A relatively thick dielectric layer **67** will reduce the capacitance between these two structures and thereby reduce the current needed to drive the excitation electrode. The various signal feedthrough conductors for the electrodes **78, 80** to the active electronic circuitry may be readily formed as would be understood by those skilled in the art. In addition, the illustrated signal polarities may be readily reversed as would also be readily understood by those skilled in the art.

The overall contact or sensing surface for the sensor **30** may desirably be about 0.5 by 0.5 inches —a size which may be readily manufactured and still provide a sufficiently large surface for accurate fingerprint sensing and identification. The sensor **30** in accordance with the invention is also fairly tolerant of dead pixels or sensing elements **30***a*. A typical sensor **30** includes an array of about 256 by 256 pixels or sensor elements, although other array sizes are also contemplated by the present invention. The sensor **30** may also be fabricated at one time using primarily conventional semiconductor manufacturing techniques to thereby significantly reduce the manufacturing costs.

Referring now additionally to FIG. **11,** functional partitioning of an apparatus **90** including the fingerprint sensor **30** is described. The fingerprint sensor apparatus **90** may be configured to provide one or more of displacement sensing of the fingerprint, provide an image present trigger, perform analog-to-digital conversion, provide full image capture and image integrity determination, provide contrast enhancement and normalization, and provide image binarization. In the illustrated embodiment, the sensor **30** is connected to a parallel processor and memory array **92,** and control processor **93** via the illustrated interface **91**. The parallel processor **92** may provide image quality and bad block determinations; provide edge enhancement and smoothing and thinning; generate ridge flow vectors, smooth the vectors and generate ridge flow characteristics as may be desired for fingerprint matching; identify the center of the fingerprint; generate, smooth and clean curves; and provide minutiae identification. The illustrated control processor **93** may provide minutiae registration and matching, minutiae storage, generate authorization codes, and communicate with the host via the illustrated interface **94**. The illustrated local non-volatile memory **95** may also be included in the apparatus **90**.

A variation of the apparatus **90** of FIG. **11** is illustrated by the apparatus **100** of FIG. **12**. This embodiment includes a two chip version of the sensor and processing electronics. The apparatus **100** includes a sensor chip **96** and an authenticator chip **97** connected via a local memory bus interface **99**. A scan control processor **98** is also included in the illustrated embodiment of FIG. **12**, while the remaining functional components are the same as in FIG. **11** and need no further description herein.

Demodulation and preliminary processing of the detected signals from the sensor **30** are further understood with reference to FIGS. **13** and **14**. Both of the illustrated circuits **110, 120** desirably use an alternating current excitation. In addition, the amplitude of the voltage on the sensor is proportional to the displacement of the local ground plane, hence, the signal has to be demodulated before further use. FIG. **13** illustrates a local comparator **112** to allow the control to manage the A/D conversion process in parallel. The processor can present a sequence of a reference voltages to an entire row or column of pixels or sensor elements **30***a* and monitor the transitions on the SigO lines. A successive approximation conversion could be implemented, first stepping large steps, and then stepping in progressively finer steps over a smaller range, as would be readily understood by those skilled in the art. The SigO output can be a binary bus connection while the SigA output is a demodulated analog signal that can be used as part of analog reference voltage generating circuit, as would also be readily understood by those skilled in the art.

The circuit **120** illustrated in FIG. **14** has storage to do localized contrast enhancement for all sensor units or pixels simultaneously. The computation can use the analog comparator **112** for a decision element. The binarized output image can be shifted out of the binary shift registers provided by the illustrated latches **113**. Alternately, the output image could by read out as with conventional memory array addressing as would be readily understood by those skilled in the art. Since the circuit **120** has its own local memory, it does not need a separate set of buffers to store the pixel data.

Variations in skin conductivity and contamination may cause phase shift of the electric field signal. Accordingly, the processing electronic circuits **110, 120** of FIGS. **13** and **14** preferably include a synchronous demodulator or detector **111** so that the overall circuit has less sensitivity to any such variations in conductivity.

Interconnections of the sensor units or pixels **30***a* in a portion of an array are schematically illustrated in FIG. **15**.

Column data transfer lines **121**, row data transfer lines **122**, and comparator reference lines **123** are shown connected to the array of sensor units **30***a*. The interconnections may be desirably made in an 8-by-8 block of sensor units, although other configurations are also contemplated by the present invention.

Further embodiments of various processor circuitry is understood with reference to FIGS. **16** and **17**. The circuit **130** of FIG. **16** includes a charge coupled device (CCD) shift register **131** which, in turn, includes a plurality of individual shift registers **135**. The shift registers **131** function as a tapped delay line to facilitate image signal processing. The registers **135** feed respective A/D converters **132** operated under control of the illustrated block processor **134**. The sensing amplifier outputs are connected to the CCD analog shift registers **135**, with one shift register per row of pixels. A row of data is then shifted out of the register either to an A/D converter **132** which serves as the active conversion device. Each pixel is converted to an 8 bit digital word as it arrives at the converter. The conversion process and the A-to-D reference voltage are under control of block processors, where each block processor may control one or more rows, such as, for example, 16 rows per each processor. A limited degree of dynamic contrast compensation can be achieved using data from the previous pixel conversion to scale the reference voltage; however, significant downstream digital image processing may still be required.

The circuit **140** of FIG. **17** is similar to that of FIG. **16**. In FIG. **17**, a comparator **141** operates under control of the illustrated block processor **134** to provide the image output signals as would be readily understood by those skilled in the art.

Turning now additionally to FIG. **18**, another aspect of the signal processing configurations in accordance with the invention is described. This circuit embodiment **150** is similar to that embodiment illustrated in FIG. **11** and described above. The circuit **150** of FIG. **18** illustratively includes a 16-by-16 array of sensor units or image cells **30***b* selectively addressed and read by the illustrated row select data input multiplexor **151**, column select bus drivers **153**, and comparator reference voltage dividers **152**. Once an image has been captured from the electric field sensing electrodes and digitized, fingerprint features can be extracted from the image. FIG. **18** illustrates a high level view of a sensor connected to a bank of digital signal processors **92**. A 128×128 pixel array, in this instance, has been partitioned into a 16×16 array of image cells **30***b*, wherein each image cell is formed of an 8×8 pixel array.

Each image cell **30***b* has a single comparator reference line that services the entire cell. When a cell **30***b* is being scanned, one of the parallel processors manages the reference voltage for that cell **30***b* and records the digitized signals for all of the sensors in that cell. During the process of scanning the sensors in the cell **30***b*, the processor can simultaneously correlate the data from the cell to generate a preliminary estimate of the ridge flow direction in that cell. In the illustrated embodiment, a control processor **93** manages the sensor signal scanning and digitization, and supervises a bank of parallel processors **92** that perform feature extraction and matching functions. The other illustrated components are similar to those discussed above with reference to FIG. **11** and, hence, need no further discussion.

Turning now additionally to FIG. **19**, a 4×4 processor matrix circuit **180**, such as might be used for a pipeline style implementation of the fingerprint minutiae processing, is illustrated. The circuit **180** includes an array of processors **184**, a sensor array input/output portion **181**, a non-volatile memory interface **183**, and the illustrated multi-processor array clock and control unit **182**. The illustrated circuit **180** may be used to identify and locate the fingerprint's unique minutiae to determine a match between a sensed fingerprint and one of a plurality of reference fingerprints. In other words, the processors **184** may match the minutiae against a set of previously stored reference minutia, to complete the identification process. When a positive identification has been made, for example, the circuit **180** may notify an external processor by sending an appropriately encrypted message over a host processor interface.

There is a general need to ensure sufficient contrast between the ridges and valleys of the fingerprint over the entire area of the fingerprint. The circuit **160** of FIG. **20** schematically illustrates a resistive network or matrix **161** including a plurality of interconnected resistors **162** for providing dynamic contrast enhancement for the array of pixels **30***a*. The effect of adjacent pixels is used to normalize the output of each pixel and while providing sufficient contrast. The circuit includes a pair of amplifiers **163**, **164** for providing the enhanced contrast output signals.

Each pixel's value is determined by comparing the sensor signal to a reference signal that sums the block reference signal with a weighted average of the signals from all of the sensors in the immediate area. The square resistive grid or matrix provides the necessary weighted average to each of the pixel comparators simultaneously. The global block reference line **165** is preferably driven with a staircase waveform while the comparator outputs are monitored for change of state. Each pixel's gray-scale value may be determined by noting which step of the staircase causes that pixel's comparator to change state as would be readily understood by those skilled in the art.

A variation for dynamic contrast enhancement is understood with reference to the circuit **170** of FIG. **21**. Dynamic contrast enhancement can also be implemented by an array **172** of capacitors **171** interconnecting the pixel nodes **174**. In this embodiment, the array **172** receives an alternating current signal derived from the synchronous demodulator **175** described in greater detail above. The capacitors **171** serve as an AC impedance network distributing and averaging the AC signals in a fashion analogous to the behavior of the resistive network **161** (FIG. **20**) for DC signals. In the AC contrast enhancing circuit **170**, the lowpass filtering that in other embodiments may be part of the demodulator circuit, is moved to the comparator **177** circuit portion. The capacitor array **172** is readily implemented using conventional semiconductor processing techniques and may offer an advantage of relatively small size as compared to the resistor array implementation described above and as would be readily appreciated by those skilled in the art.

The resistive matrix circuit **160** and capacitor matrix circuit **170** may provide weighting for image contrast enhancement. An alternative is to conduct such enhancement via downstream software which may take a relatively long time to fully process.

Accordingly, the resistor matrix and capacitor matrix arrangement may provide greater overall processing speed. In addition, such preliminary processing at the sensor **30** may allow relaxation of A/D conversion from an 8 bit AD converter to a 1 bit converter in some embodiments, while still providing high speed and at a relatively low cost. For example, processing of the fingerprint image and determination of a match may desirably take only several seconds for certain applications to avoid user frustration.

Referring now additionally to FIG. **22**, another aspect of the invention is described wherein the sensor **30** may be contained within a secure sensor package **190**. The sensor **30** is desirably mounted to prevent flexing or shifting which may stress the chip or its electrical connections. More particularly, the overall package may include a tamper resistant housing **191** as would be readily understood by those skilled in the art. For example, the housing **191** may be formed of a hard plastic material or metal that is strong and resistant to cutting, abrading or sawing. Alternately, the housing **191** may be a material which crumbles and destroys its internal circuit components if cutting, dissolution, or other forms of entry are attempted.

Those of skill in the art will appreciate other variations of tamper resistant housings **191** as contemplated by the present invention.

The sensor package **190** also includes the illustrated substrate **195**, processor **192**, destructible memory **195**, and encrypted output circuit **194**. More particularly, the encrypted output circuit **194** provides an output signal that can only be decrypted by the intended downstream device. Such encryption techniques will be readily understood by those skilled in the art and may include the use of various keys, passwords, codes, etc. as will also be readily understood by those skilled in the art. For example, U.S. Pat. Nos. 4,140,272; 5,337,357; 4,993,068 and 5,436,972 each disclose various approaches to encryption and the disclosures of these patents are incorporated herein in their entirety by reference.

The output of the sensor package **190** may be communicated to associated downstream decryption equipment via electrically conductive leads or pins, or may be inductively or optically coupled to associated equipment as will be readily understood by those skilled in the art. As would also be understood by those skilled in the art, electrical or other types of protection may be provided on the encrypted output portion to ensure that data, such as a database of fingerprints stored on the memory **193**, is not readily readable by external connections and/or signal manipulations.

The sensor **30** and processor **192** may be configured to provide any of a range of integral sensor processing features. For example, the encrypted output may be a raw image, a processed image, fingerprint minutiae data, a yes/no match indication, or personal identification and digital signature keys as would be readily understood by those skilled in the art.

The illustrated sensor package **190** also includes a bead **196** of sealing material at the interface between the upper dielectric layer **52** of the sensor **30** and the adjacent portions of the housing **191**. Other sealing arrangements are also contemplated by the present invention, for desirably providing a fluid tight seal at the interface between the exposed upper dielectric layer and the adjacent housing portions. In addition, a cleaning liquid may be used to routinely clean the window and reduce the contamination thereof. Since various alcohols, such as isopropyl alcohol are likely to be used as cleaning solutions, the housing **191** and sealing bead **196** are desirably resistant to such chemicals as would be readily understood by those skilled in the art.

Turning now additionally to FIG. **23** another sensor package **220** is illustrated, and the problems and solutions with respect to an integrated circuit package in accordance with the present invention are discussed. As would be readily understood by those skilled in the art, a fingerprint sensor integrated circuit presents a special packaging difficulty since it has to be touched by the finger being scanned.

It is typically desired to avoid touching of an integrated circuit in conventional integrated circuit fabrication, in part, because of potential contamination. The main contaminants of concern are sodium and the other alkaline metals. These contaminants may cause mobile ions in the SiO_2 layers that are typically used to passivate the integrated circuit. The resulting oxide charge degrades device characteristics especially in MOS technology.

One conventional approach to controlling mobile ionic contamination uses hermetic packaging with a phosphorus-doped passivation layer over the integrated circuit. The phosphorus doping reduces contaminant mobility by trapping mechanisms as would be readily understood by those skilled in the art. Plastic packaging has now become more widespread, and a silicon nitride passivation layer may be used with the plastic packaging. Silicon nitride may greatly reduce the permeability to contaminants to permit direct contact between the finger of the user and the integrated circuit. Accordingly, silicon nitride may preferably be used as a passivation layer of the fingerprint sensor in accordance with the present invention.

A fingerprint sensor as in the present invention also raises several unique packaging requirements including: the package needs to be open to enable finger-to-sensor die contact; the package should be physically strong in order to withstand rough use; the package and die should be able to withstand repeated cleaning with detergent and/or disinfectant solutions, and including scrubbing; the die should be able to withstand contact with a wide variety of organic and inorganic contaminants, and should be able to withstand abrasion; and finally the package should be relatively inexpensive.

The illustrated package **220** of FIG. **23** addresses these packaging issues. The package **220** includes an integrated circuit die **221** mounted on a metal paddle **222** that is connected to the leadframe **223** during injection molding of the surrounding plastic material **191** of the package. Connections are made by bond wires **227** and the lead frame **223** to the outwardly extending leads **228** as would be readily understood by those skilled in the art. The upper surface of the plastic housing **191** includes an integrally molded opening **52** which permits contact to the die **221**. The adhesion between the plastic molding compound and the adjacent upper surface portions of the die creates a seal in this illustrated embodiment. Accordingly, no separate sealing compound or manufacturing step may be needed as would be readily understood by those skilled in the art.

The integrated circuit die **221** may also include a passivation layer **224** of silicon nitride for reasons highlighted above. In addition, as shown in the illustrated sensor package **220**, the die **221** may be provided with a second protective coating **225**. Each of the coatings **224, 225** are desirably relatively thin, such as on the order of about a micrometer, in order to retain sensor sensitivity. The outer coating **225** may be an organic material, such as polyimide or PTFE (Teflon™) which yields advantages in wear resistance and physical protection. Inorganic coatings, such as silicon carbide or amorphous diamond, may also be used for the outer layer **225** and may greatly enhance wear resistance, especially to abrasive particles. In addition, the material of the protective die coating **225** is preferably compatible with standard IC pattern definition methods in order to enable bond pad etching, for example.

The bond pads on the integrated circuit die **221** may be provided by aluminum. Another perhaps more preferable approach seals the pads with a gold plug, as may be applied

by electroplating, as would be readily understood by those skilled in the art. As would also be readily understood by those skilled in the art, in order to reduce the height created by the looped bond wires **227**, the die **221** may be directly flip-chip bonded in another embodiment of the invention, not shown. As would be readily understood by those skilled in the art, the sensor package **220** in other embodiments may be manufactured using tape automated bonding techniques.

Returning again briefly to FIG. **22**, yet another aspect of the sensor package **190** is that the memory **198** and/or other integrated circuit components may be made to destruct or be rendered secure upon breach of the housing **191**, for example. A coating **193** of material may be applied to the integrated circuit die(s) that causes destruction of the die if the coating is dissolved away as would be readily understood by those skilled in the art. The memory **193** may also self-destruct or empty its contents upon exposure to light or upon removal of a sustaining electrical current. Those of skill in the art will readily appreciate other approaches to ensuring the integrity of the data and processing capabilities of the sensor package **190** in accordance with the present invention. Accordingly, the present invention provides that sensitive data, such as a database of authorized fingerprints, encryption keys, or authorization codes, are not readily stolen from the sensor package **190**. In addition, although the sensor package **190** may desirably incorporate the electrical field sensor **30** as described extensively herein, other sensors are also contemplated for inclusion with a secure sensor package in accordance with this aspect of the invention.

The various embodiments of the sensor **30** and its associated processing circuitry may implement any of a number of conventional fingerprint matching algorithms. For example, a suitable fingerprint matching algorithm and indexing approach for quick and efficient searching is described in copending patent application entitled "Methods and Related Apparatus for Fingerprint Indexing and Searching", having Ser. No. 08/589,064, assigned to the assignee of the present invention and the entire disclosure of which is incorporated herein by reference in its entirety.

As would be readily understood by those skilled in the art, fingerprint minutiae, that is, the branches or bifurcations and end points of the fingerprint ridges, are often used to determine a match between a sample print and a reference print database. Such minutiae matching may be readily implemented by the processing circuitry of the present invention as would be readily understood by those skilled in the art. For example, U.S. Pat. Nos. 3,859,633 and 3,893,080 both to Ho et al. are directed to fingerprint identification based upon fingerprint minutiae matching. U.S. Pat. No. 4,151,512 to Riganati et al., for further example, describes a fingerprint classification method using extracted ridge contour data. U.S. Pat. No. 4,185,270 to Fischer II et al. discloses a process for encoding and verification also based upon minutiae. In addition, U.S. Pat. No. 5,040,224 to Hara discloses an approach to preprocessing fingerprints to correctly determine a position of the core of each fingerprint image for later matching by minutiae patterns. The entire disclosures of each of these U.S. patents are incorporated herein by reference.

Turning now lastly to FIGS. **24–26** another significant aspect of the present invention is described. Because of the relatively fast and efficient processing of a fingerprint image provided by above identified sensor **30** and associated circuitry of the invention, the user may be provided with nearly real-time feedback regarding positioning of his finger on a fingerprint sensor, such as the illustrated electric field sensor **30**. Accordingly, the user may quickly and accurately reposition his finger, have his identification accurately determined, and promptly move forward with the intended task. In the past only a simple go or no-go indication has been described for a user as in U.S. Pat. No. 4,947,443 to Costello, for example, and with such an indication most likely taking a relatively long time. It is generally understood that unless such an indication can be given within several seconds, user frustration is likely to rise dramatically with any further passage of time. Moreover, a simple go/no-go indication may only prompt the user to try again without any useful guidance on what may be causing the no-go indication.

The apparatus **200** (FIG. **24**) illustratively includes a fingerprint sensor **30** operatively connected to an image processor **201**. Along the lines as discussed above, the image processor **201** may include the tapped delay line or other functional center point calculator **202** for determining a center point from the sensed fingerprint as will be readily appreciated by those skilled in the art. The location of the center point relative to a predetermined reference center point may be determined and an indication given the user via a position indicator **203**. The image may also be further analyzed, and if the applied finger pressure is too great or too little, such an indication may also be given to the user. Accordingly, potential user frustration may be significantly reduced. A need to clean the sensor may also be effectively communicated to the user if repositioning and/or pressure changes are ineffective, such as after a predetermined number of attempts.

Turning now more particularly to FIG. **25**, a practical implementation of the position feedback sensing and indication is further described as applied in a computer workstation, such as the illustrated notebook computer **35** of the type including a keyboard **36** and display **37**. Those of skill in the art will recognize the applicability of this aspect of the invention to many types of fixed and portable computer workstations in addition to the illustrated notebook computer.

In the illustrated embodiment, the fingerprint sensor **30** receives the finger of the user. The processor of the computer in cooperation with the fingerprint sensor **30** generates a display of the fingerprint image **206** along with its center point **205** on an image of a window **207** on the display **37**. In the illustrated embodiment, the display also includes a target center point **208** to assist the user is repositioning his finger for an accurate reading.

In addition to the visual image indication, a further indication may be given by display of the words "move upward" and "move left" along with the illustrated associated directional arrows. An indication may also be given concerning a desired pressure, such as the illustrated words "increase pressure".

Yet another variation of the feedback and pressure indications may be in the form of synthetically generated speech messages issued from a speaker **39** mounted within the housing of the computer. For example, the generated voice messages illustratively include an annunciation to "move finger up and to the left" and "increase finger pressure". Other helpful messages are also contemplated by the present invention.

Still another embodiment of finger position feedback sensing and indication is understood with further reference to the apparatus **210** of FIG. **26**. In this embodiment, the sensor **30** is used to operate an access controller **211** which, in turn, may operate a door, for example, to permit a

properly identified user to enter. Simple visual indications in the form of LEDs **212**, **213** for up and down motion, and left and right motion, respectively, may be provided to indicate to the user the proper positioning or repositioning of his finger. The illustrated embodiment also includes a plurality of LEDs **214** for indication of pressure. Those of skill in the art will readily appreciate many other variations and alternate embodiments of the feedback sensing and positioning in accordance with this aspect of the present invention.

Many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

That which is claimed is:

1. A fingerprint sensor comprising:

an array of electric field sensing electrodes;

a dielectric layer on a first surface of said array of electric field sensing electrodes, said dielectric layer for receiving a finger adjacent thereto; and

coherent drive means for applying a coherent electric field drive signal to said array of electric field sensing electrodes and adjacent portions of the finger so that said array of electric field sensing electrodes produce a fingerprint image output signal, said coherent drive means comprising

a second dielectric layer on a second surface of said array of electric field sensing electrodes opposite the first surface, and

a common drive electrode extending beneath at least a plurality of electric field sensing electrodes of said array of electric field sensing electrodes with the second dielectric layer therebetween so that the electric field drive signal radiates vertically between said common drive electrode and electric field sensing electrodes.

2. A fingerprint sensor according to claim **1** wherein said coherent drive means further comprises a drive circuit for powering said common drive electrode to generate the coherent electric field drive signal having a predetermined frequency.

3. A fingerprint sensor according to claim **1** further comprising a finger electrode positioned adjacent said dielectric layer for contact with the finger.

4. A fingerprint sensor according to claim **1** further comprising a respective shield electrode associated with each of said electric field sensing electrodes for shielding each electric field sensing electrode from adjacent sensing electrodes.

5. A fingerprint sensor according to claim **4** wherein each shield electrode comprises an electrically conductive layer surrounding a respective electric field sensing electrode with a dielectric layer therebetween.

6. A fingerprint sensor according to claim **4** further comprising active shield driving means for actively driving each of said shield electrodes.

7. A fingerprint sensor according to claim **6** wherein said active shield driving means comprises an amplifier operatively connected to each electric field sensing electrode and its associated shield electrode for actively driving the shield electrode with a portion of an output signal from said amplifier.

8. A fingerprint sensor according to claim **1** further comprising synchronous demodulator means operatively connected to said electric field sensing electrodes for synchronously demodulating signals therefrom.

9. A fingerprint sensor according to claim **1** further comprising dynamic contrast enhancing means operatively connected to said electric field sensing electrodes for dynamically enhancing contrast and uniformity of the fingerprint image output signal.

10. A fingerprint sensor according to claim **9** wherein said dynamic contrast enhancing means comprises:

a capacitor matrix operatively connected to said electric field sensing electrodes; and

alternating current capacitor matrix drive means for driving said capacitor matrix.

11. A fingerprint sensor according to claim **10** wherein said alternating current capacitor matrix drive means comprises a synchronous demodulator.

12. A fingerprint sensor according to claim **9** wherein said dynamic contrast enhancing means comprises a resistor matrix operatively connected to said electric field sensing electrodes.

13. A fingerprint sensor according to claim **1** further comprising an amplifier operatively connected to each electric field sensing electrode.

14. A fingerprint sensor according to claim **1** further comprising multiplexing means for selectively reading each of said electric field sensing electrodes.

15. A fingerprint sensor according to claim **1** further comprising:

a substrate; and

an active semiconductor layer on said substrate comprising a plurality of semiconductor devices operatively connected to said electric field sensing electrodes.

16. A fingerprint sensor according to claim **15** further comprising package means for enclosing said substrate, said active semiconductor layer, said electric field sensing electrodes, and said dielectric layer; and wherein said package means has an opening therethrough in registry with said dielectric layer.

17. A fingerprint sensor comprising:

an array of electric field sensing electrodes;

a dielectric layer on said electric field sensing electrodes, said dielectric layer for receiving a finger adjacent thereto;

a respective shield electrode associated with each of said electric field sensing electrodes for shielding each electric field sensing electrode from adjacent electric field sensing electrodes; and

drive means for applying an electric field drive signal to said electric field sensing electrodes and adjacent portions of the finger, said drive means comprising a common drive electrode extending beneath at least a plurality of electric field sensing electrodes of said array of electric field sensing electrodes so that the electric field drive signal radiates vertically between said common drive electrode and electric field sensing electrodes for causing said electric field sensing electrodes to produce a fingerprint image output signal.

18. A fingerprint sensor according to claim **17** wherein each shield electrode comprises an electrically conductive layer surrounding a respective electric field sensing electrode with a dielectric layer therebetween.

19. A fingerprint sensor according to claim **17** further comprising active shield driving means for actively driving each of said shield electrodes.

20. A fingerprint sensor according to claim **19** wherein said active shield driving means comprises an amplifier

operatively connected to each electric field sensing electrode and its associated shield electrode for actively driving the shield electrode with a portion of an output signal from the amplifier.

21. A fingerprint sensor according to claim **17** wherein said drive means further comprises a drive circuit for powering said common drive electrode to generate the electric field drive signal having a predetermined frequency.

22. A fingerprint sensor according to claim **17** further comprising a finger electrode positioned adjacent said dielectric layer for contact with the finger.

23. A fingerprint sensor according to claim **17** further comprising synchronous demodulator means operatively connected to said electric field sensing electrodes for synchronously demodulating signals therefrom.

24. A fingerprint sensor according to claim **17** further comprising dynamic contrast enhancing means operatively connected to said electric field sensing electrodes for dynamically enhancing contrast and uniformity of the fingerprint image output signal.

25. A fingerprint sensor according to claim **24** wherein said dynamic contrast enhancing means comprises:

a capacitor matrix operatively connected to said electric field sensing electrodes; and

alternating current capacitor matrix drive means for driving said capacitor matrix.

26. A fingerprint sensor according to claim **25** wherein said alternating current capacitor matrix drive means comprises a synchronous demodulator.

27. A fingerprint sensor according to claim **24** wherein said dynamic contrast enhancing means comprises a resistor matrix operatively connected to said electric field sensing electrodes.

28. A fingerprint sensor according to claim **17** further comprising:

a substrate;

an active semiconductor layer on said substrate comprising a plurality of semiconductor devices operatively connected to said electric field sensing electrodes; and

package means for enclosing said substrate, said active semiconductor layer, said electric field sensing electrodes, and said dielectric layer, and wherein said package means has an opening therethrough in registry with said dielectric layer.

29. A fingerprint sensor comprising:

an array of electric field sensing electrodes;

a dielectric layer on said electric field sensing electrodes, said dielectric layer for receiving a finger adjacent thereto;

a respective shield electrode comprising electrically conductive material surrounding each of said electric field sensing electrodes for shielding each electric field sensing electrode from adjacent electric field sensing electrodes;

active shield driving means for actively driving each of said shield electrodes; and

drive means for applying an electric field drive signal to said electric field sensing electrodes and adjacent portions of the finger, said drive means comprising a common drive electrode extending beneath at least a plurality of electric field sensing electrodes of said array of electric field sensing electrodes so that the electric field drive signal radiates vertically between said common drive electrode and electric field sensing electrodes for causing said electric field sensing electrodes to produce a fingerprint image output signal.

30. A fingerprint sensor according to claim **29** wherein said active shield driving means comprises an amplifier operatively connected to each electric field sensing electrode and its associated shield electrode for actively driving the shield electrode with a portion of an output signal from the amplifier.

31. A fingerprint sensor according to claim **29** wherein said drive means further comprises a drive circuit for powering said common drive electrode to generate the electric field drive signal having a predetermined frequency.

32. A fingerprint sensor according to claim **29** further comprising a finger electrode positioned adjacent said dielectric layer for contact with the finger.

33. A fingerprint sensor according to claim **29** further comprising synchronous demodulator means operatively connected to said electric field sensing electrodes for synchronously demodulating signals therefrom.

34. A fingerprint sensor according to claim **29** further comprising dynamic contrast enhancing means operatively connected to said electric field sensing electrodes for dynamically enhancing contrast and uniformity of the fingerprint image output signal.

35. A fingerprint sensor according to claim **34** wherein said dynamic contrast enhancing means comprises:

a capacitor matrix operatively connected to said electric field sensing electrodes; and

alternating current capacitor matrix drive means for driving said capacitor matrix.

36. A fingerprint sensor according to claim **35** wherein said alternating current capacitor matrix drive means comprises a synchronous demodulator.

37. A fingerprint sensor according to claim **34** wherein said dynamic contrast enhancing means comprises a resistor matrix operatively connected to said electric field sensing electrodes.

38. A fingerprint sensor according to claim **29** further comprising:

a substrate;

an active semiconductor layer on said substrate comprising a plurality of semiconductor devices operatively connected to said electric field sensing electrodes and shield electrodes; and

package means for enclosing said substrate, said active semiconductor layer, said electric field sensing electrodes and shield electrodes, and said dielectric layer, and wherein said package means has an opening therethrough in registry with said dielectric layer.

39. A computer workstation comprising:

a housing;

a computer processor positioned within said housing;

a display operatively connected to said computer processor;

a keyboard operatively connected to said computer processor; and

fingerprint sensor means operatively connected to said computer processor and mounted within said housing for protection thereby, said fingerprint sensor means comprising a finger sensing surface exposed through an opening in said housing;

said computer processor comprising access control means for permitting operation of the computer workstation only upon determining a match between a fingerprint sensed by said fingerprint sensor means and an authorized reference fingerprint;

said fingerprint sensor means comprising

an array of electric field sensing electrodes,

a dielectric layer on a first surface of said array of electric field sensing electrodes, said dielectric layer for receiving a finger adjacent thereto, and

drive means for applying an electric field drive signal to said array of electric field sensing electrodes and adjacent portions of the finger so that said array of electric field sensing electrodes produce a fingerprint image output signal, said drive means comprising a second dielectric layer on a second surface of said array of electric field sensing electrodes opposite the first surface, and a common drive electrode extending beneath at least a plurality of electric field sensing electrodes of said array of electric field sensing electrodes with the second dielectric layer therebetween so that the electric field drive signal radiates vertically between said common drive electrode and electric field sensing electrodes.

40. A computer workstation according to claim **39** wherein said drive means further comprises a coherent drive circuit for powering said common drive electrode to generate a coherent electric field drive signal having a predetermined frequency.

41. A computer workstation according to claim **39** further comprising a respective shield electrode associated with each of said electric field sensing electrodes for shielding each electric field sensing electrode from adjacent sensing electrodes.

42. A computer workstation according to claim **41** further comprising active shield driving means for actively driving each of said shield electrodes.

43. A computer workstation according to claim **39** further comprising synchronous demodulator means operatively connected to said electric field sensing electrodes for synchronously demodulating signals therefrom.

44. A computer workstation according to claim **39** further comprising dynamic contrast enhancing means operatively connected to said electric field sensing electrodes for dynamically enhancing contrast and uniformity of the fingerprint image output signal.

45. A method for sensing a fingerprint and generating a fingerprint image output signal, the method comprising the steps of:

providing an array of electric field sensing electrodes with a dielectric layer on a first surface of said array of electric field sensing electrodes for receiving a finger adjacent thereto, and further comprising a second dielectric layer on a second surface of said array of electric field sensing electrodes opposite the first surface, and a common drive electrode extending beneath at least a plurality of said array of electric field sensing electrodes with the second dielectric layer therebetween; and

applying a coherent electric field drive signal to said array of electric field sensing electrodes and adjacent portions of the finger using the common drive electrode so that the electric field drive signal radiates vertically between the common drive electrode and electric field sensing electrodes to thereby cause said array of electric field sensing electrodes to produce a fingerprint image output signal.

46. A method according to claim **45** further comprising the step of shielding said electric field sensing electrodes by positioning a respective shield electrode surrounding each of said electric field sensing electrodes to shield each electric field sensing electrode from adjacent electric field sensing electrodes.

47. A method according to claim **46** further comprising the step of actively driving each of said shield electrodes with a portion of an output signal from an amplifier associated with each electric field sensing electrode.

48. A method according to claim **45** further comprising the step of synchronously demodulating signals from said electric field sensing electrodes.

49. A method according to claim **45** further comprising the step of dynamic enhancing contrast and uniformity of the fingerprint image output signal.

50. A method for sensing a fingerprint and generating a fingerprint image output signal, the method comprising the steps of:

providing an array of electric field sensing electrodes with a dielectric layer on said electric field sensing electrodes for receiving a finger adjacent thereto and a common drive electrode extending beneath at least a plurality of said array of electric field sensing electrodes;

applying an electric field drive signal to said electric field sensing electrodes and adjacent portions of the finger using the common drive electrode so that the electric field drive signal radiates vertically between the common drive electrode and electric field sensing electrodes to thereby cause said electric field sensing electrodes to produce a fingerprint image output signal; and

shielding said electric field sensing electrodes by positioning a respective shield electrode surrounding each of said electric field sensing electrodes to shield each electric field sensing electrode from adjacent sensing electrodes.

51. A method according to claim **50** further comprising the step of actively driving each of said shield electrodes with a portion of an output signal from an amplifier associated with each electric field sensing electrode.

* * * * *

EXHIBIT E

US006259804B1

(12) **United States Patent**
Setlak et al.

(10) **Patent No.: US 6,259,804 B1**
(45) **Date of Patent: *Jul. 10, 2001**

(54) **FINGERPRINT SENSOR WITH GAIN CONTROL FEATURES AND ASSOCIATED METHODS**

(75) Inventors: **Dale R. Setlak**, Melbourne; **John Cornett**, Melbourne Beach; **Brian Kilgore**, Melbourne; **Daryl Williams**, Palm Bay; **Dave Gebauer**, West Melbourne, all of FL (US)

(73) Assignee: **Authentic, Inc.**, Melbourne, FL (US)

(*) Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **08/858,142**

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(52) **U.S. Cl.** **382/124**; 382/126
(58) **Field of Search** 382/124, 125, 382/168, 172, 270, 274, 126, 282, 287; 341/110, 118, 126, 139, 155; 348/294

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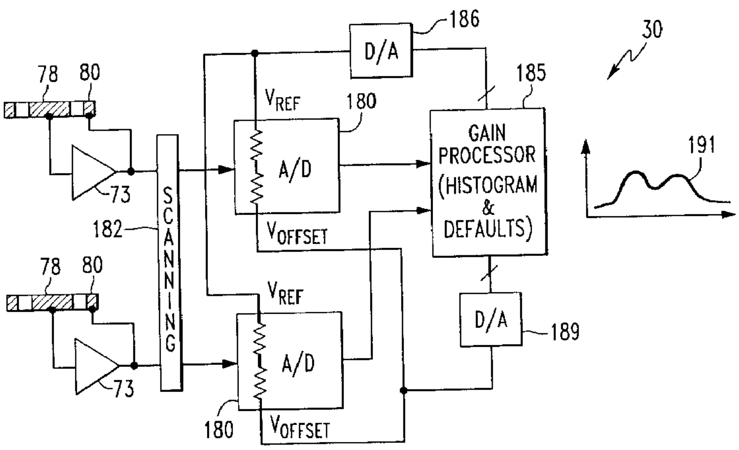
Primary Examiner—Phuoc Tran
(74) *Attorney, Agent, or Firm*—Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A.

(57) **ABSTRACT**

A fingerprint sensor includes an array of fingerprint sensing elements; analog-to-digital (A/D) converters having a controllable range; a scanner to perform sequential A/D conversions of predetermined ones of the array of fingerprint sensing elements; and a range determining and setting circuit for controlling the range of the A/D converters based upon prior A/D conversions to thereby provide enhanced conversion resolution. A plurality of A/D converters are preferably used for simultaneously converting analog signals from a corresponding plurality of fingerprint sensing elements. The A/D converters may include at least one reference voltage input for permitting setting of first and second points of the range. The range scale determining and setting circuit may generate a histogram based upon prior A/D conversions. In addition, the range scale determining and setting circuit may set a default range for initial ones of the fingerprint sensing elements.

26 Claims, 6 Drawing Sheets



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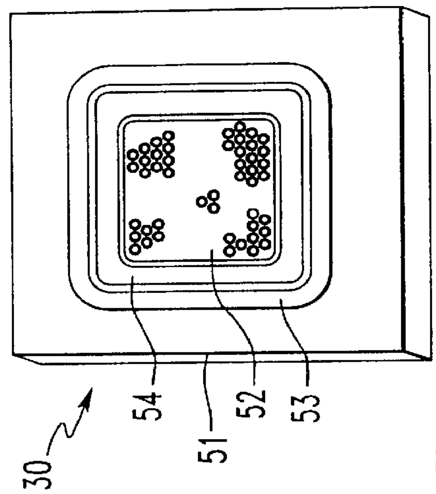
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54
51
52
53

FIG. 1

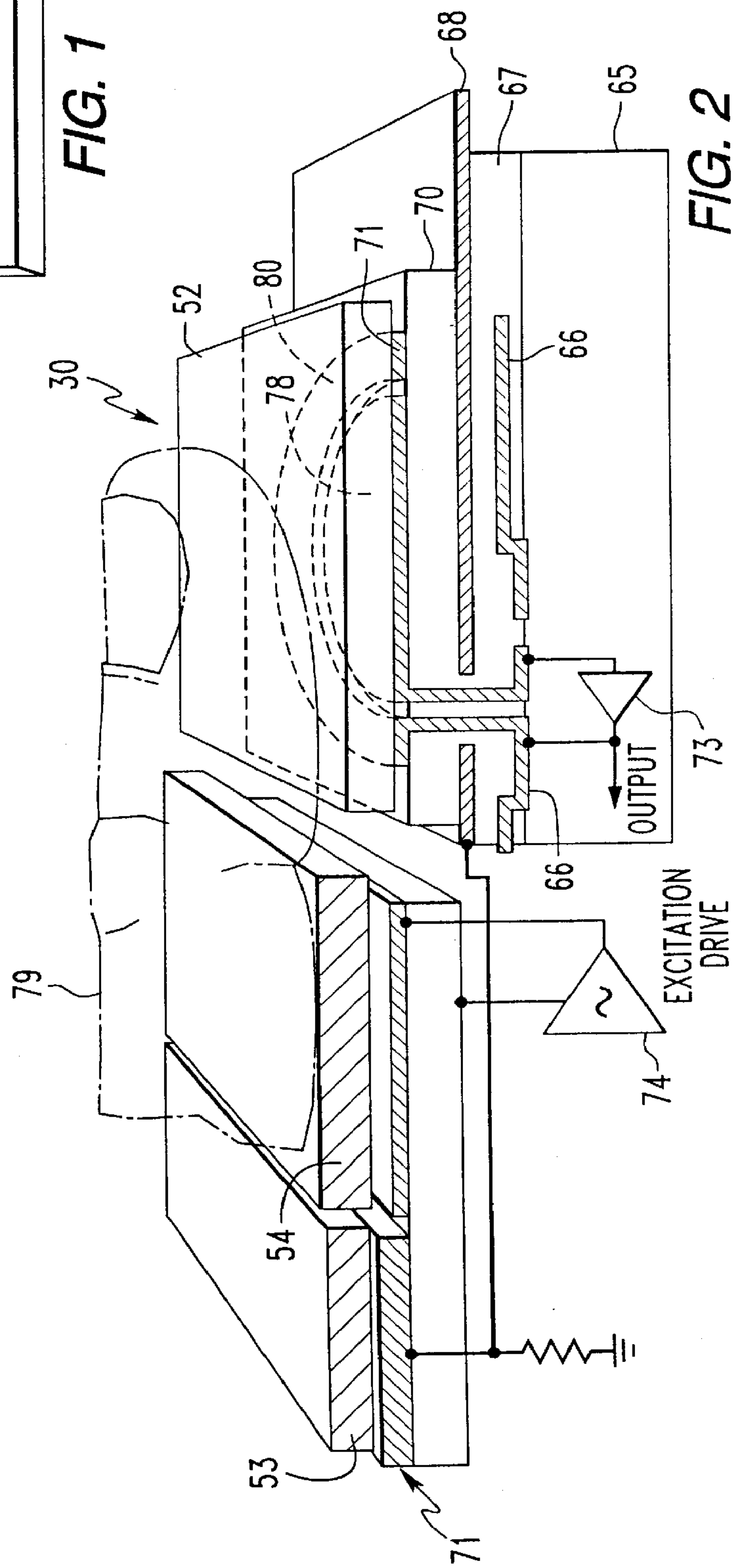
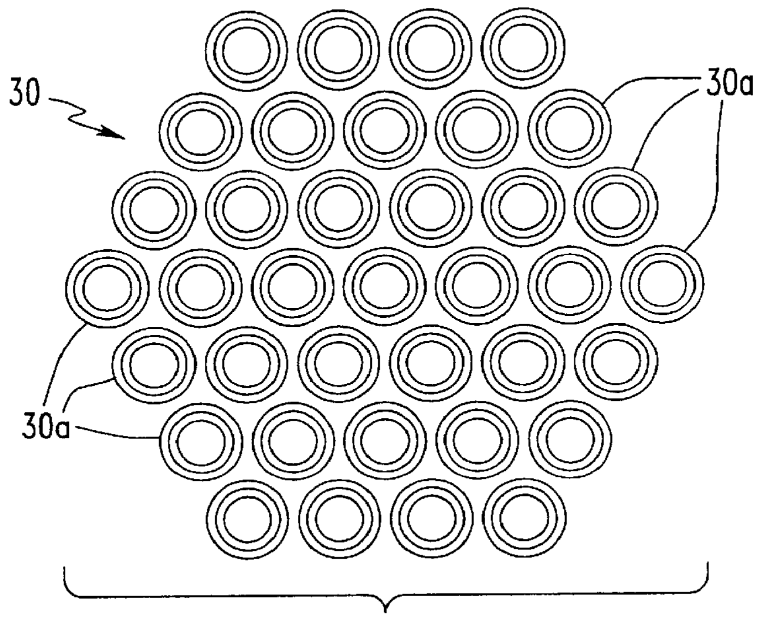

68
67
65
70
71
80
52
30
78
66
73
OUTPUT
66
EXCITATION
DRIVE
74
79
54
53
71

FIG. 2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30a
30a

FIG.3

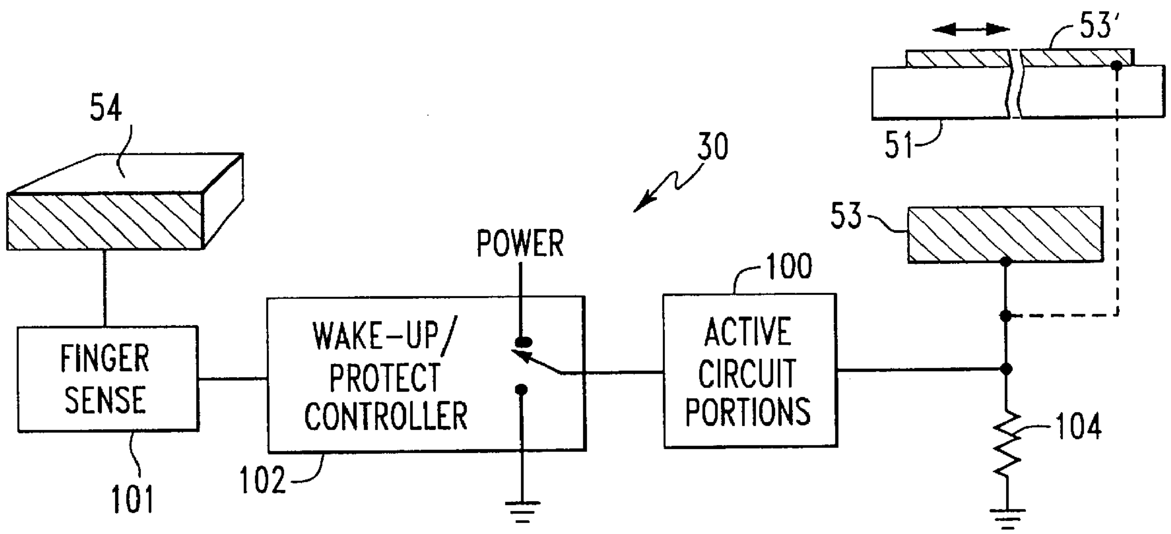
54
30
53'
51
53
POWER
100
FINGER
SENSE
WAKE-UP/
PROTECT
CONTROLLER
ACTIVE
CIRCUIT
PORTIONS
104
101
102

FIG.4

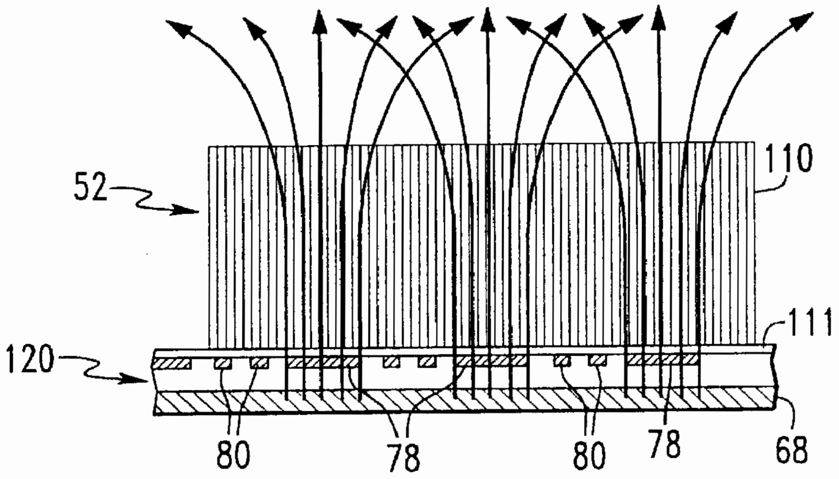

FIG. 5

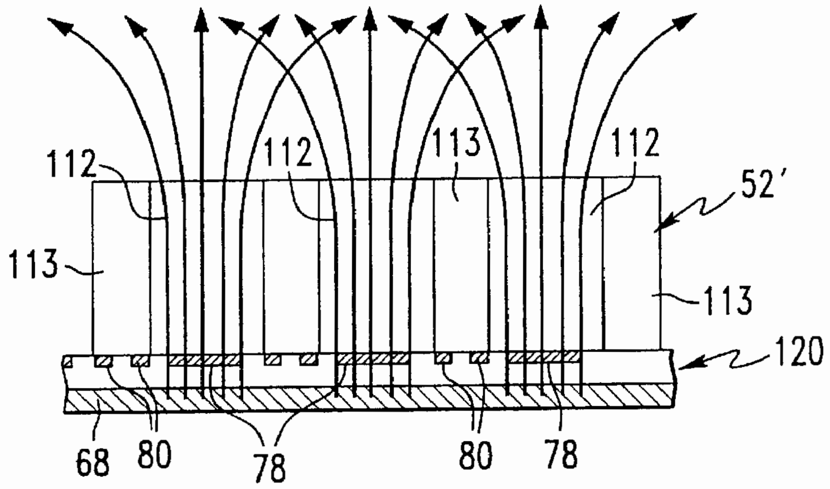

FIG. 6

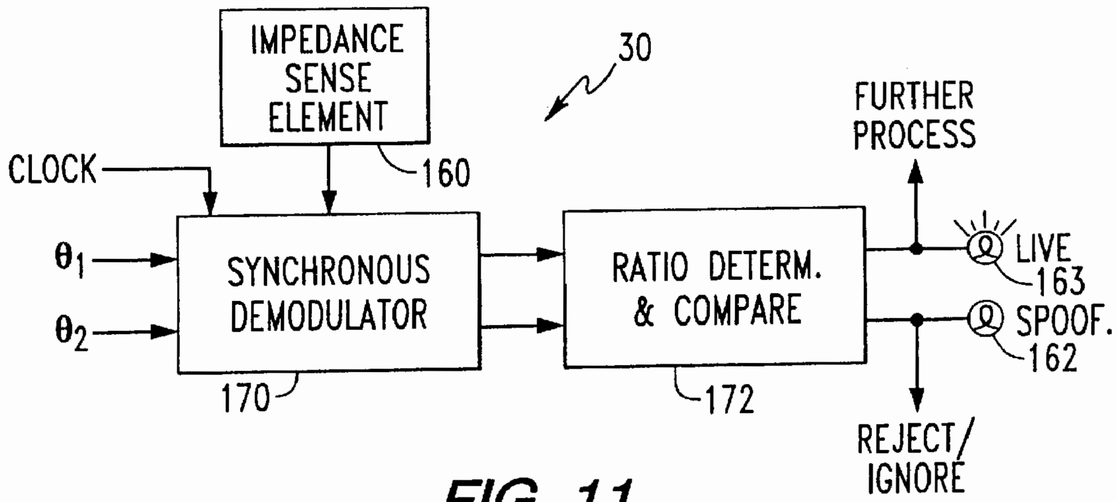

FIG. 11

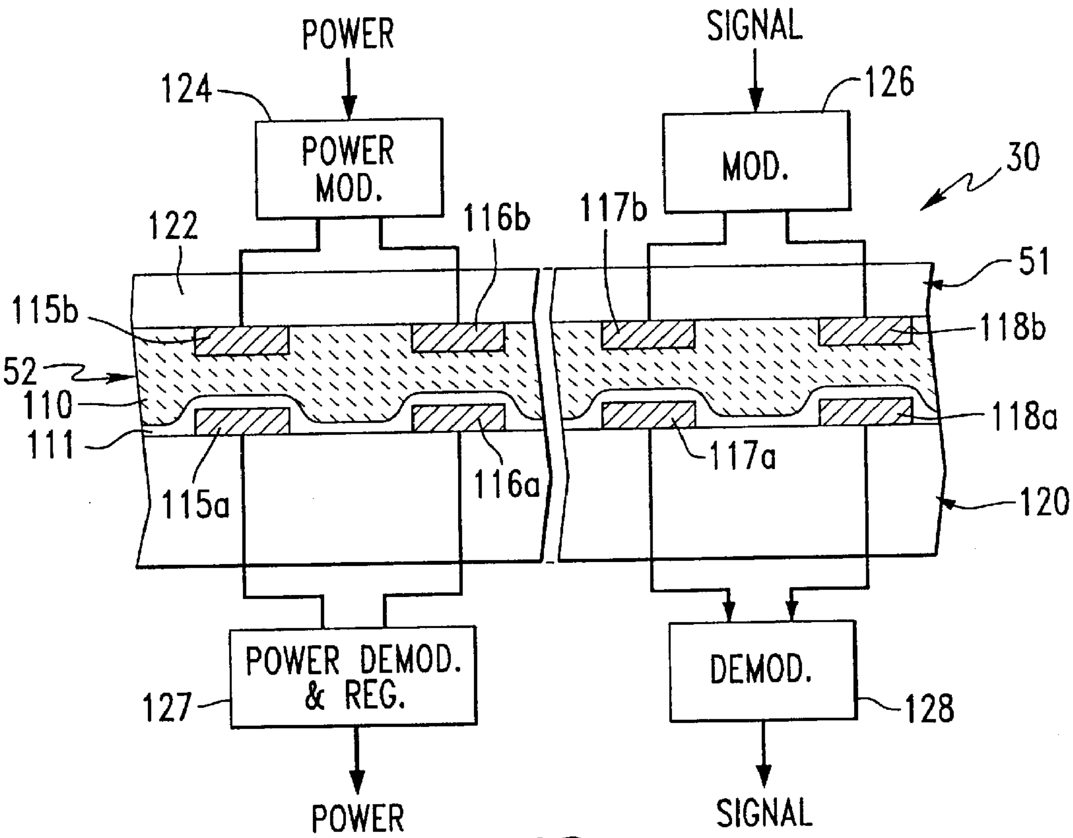
POWER
124
POWER MOD.
SIGNAL
126
MOD.
30
122
116b
117b
51
115b
118b
52
110
111
118a
117a
115a
116a
120
POWER DEMOD. & REG.
127
DEMOD.
128
POWER
SIGNAL

FIG. 7

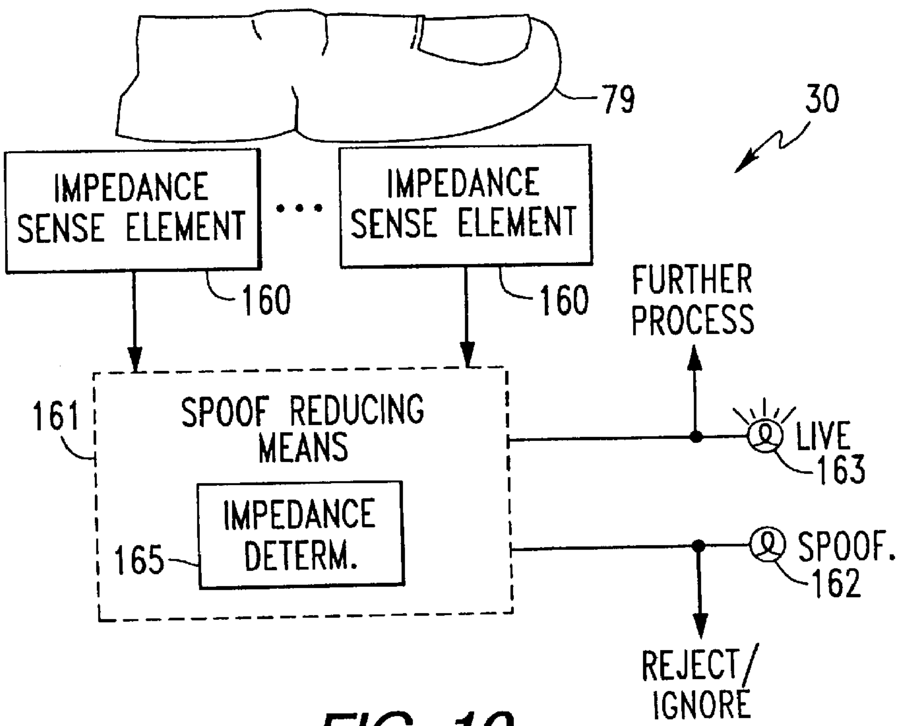
79
30
IMPEDANCE SENSE ELEMENT
IMPEDANCE SENSE ELEMENT
160
160
FURTHER PROCESS
161
SPOOF REDUCING MEANS
LIVE
163
IMPEDANCE DETERM.
165
SPOOF.
162
REJECT/ IGNORE

FIG. 10

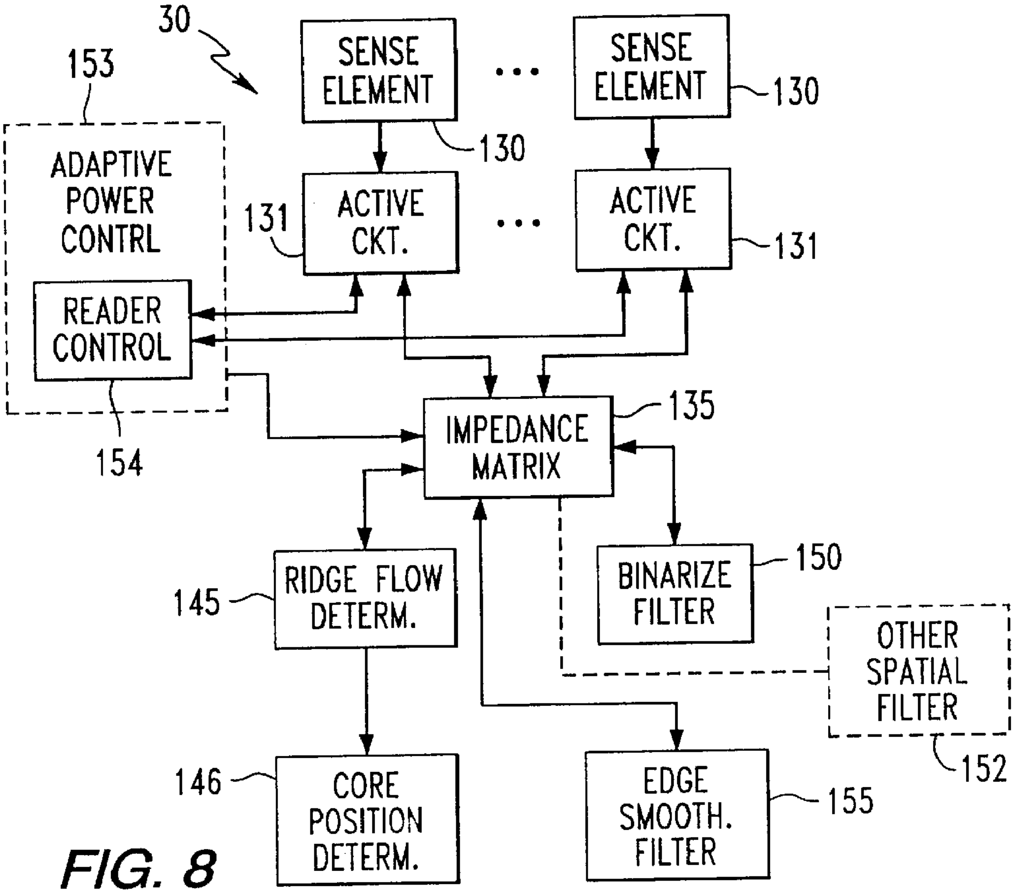
30
153
SENSE ELEMENT
SENSE ELEMENT
130
130
ADAPTIVE POWER CONTRL
131
ACTIVE CKT.
ACTIVE CKT.
131
READER CONTROL
154
IMPEDANCE MATRIX
135
RIDGE FLOW DETERM.
145
BINARIZE FILTER
150
OTHER SPATIAL FILTER
152
146
CORE POSITION DETERM.
EDGE SMOOTH. FILTER
155

FIG. 8

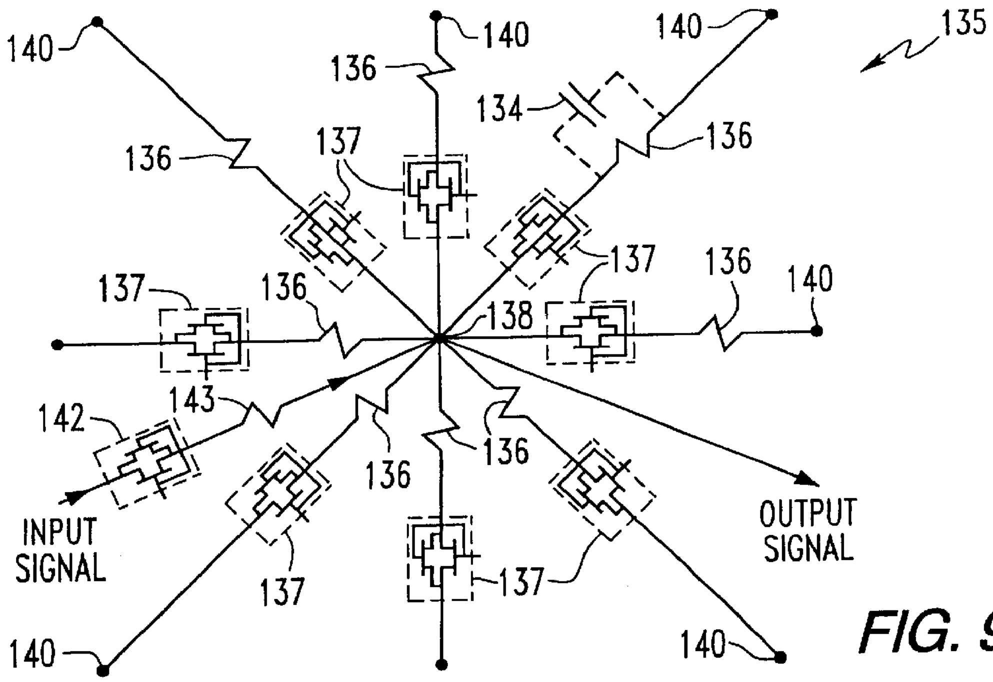
140
140
140
135
136
134
136
136
137
137
137
136
136
140
138
142
143
136
136
INPUT SIGNAL
137
137
OUTPUT SIGNAL
140
140

FIG. 9

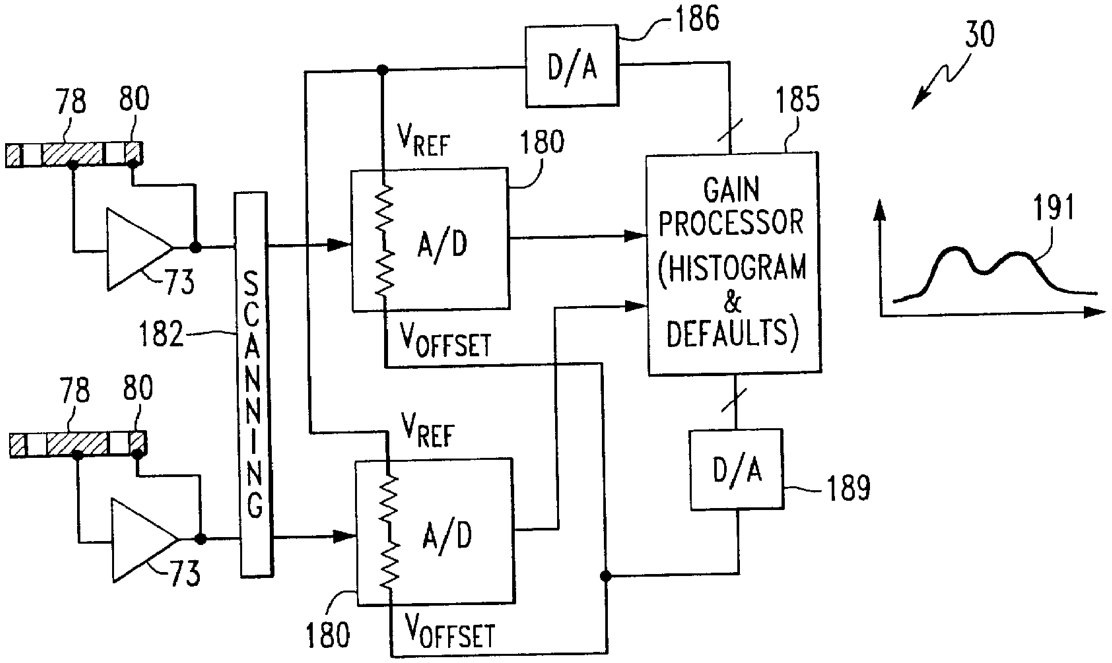
186
D/A
30
78
80
V_{REF}
180
185
GAIN PROCESSOR (HISTOGRAM & DEFAULTS)
A/D
191
73
182
SCANNING
V_{OFFSET}
78
80
V_{REF}
D/A
189
A/D
73
180
V_{OFFSET}

FIG. 12

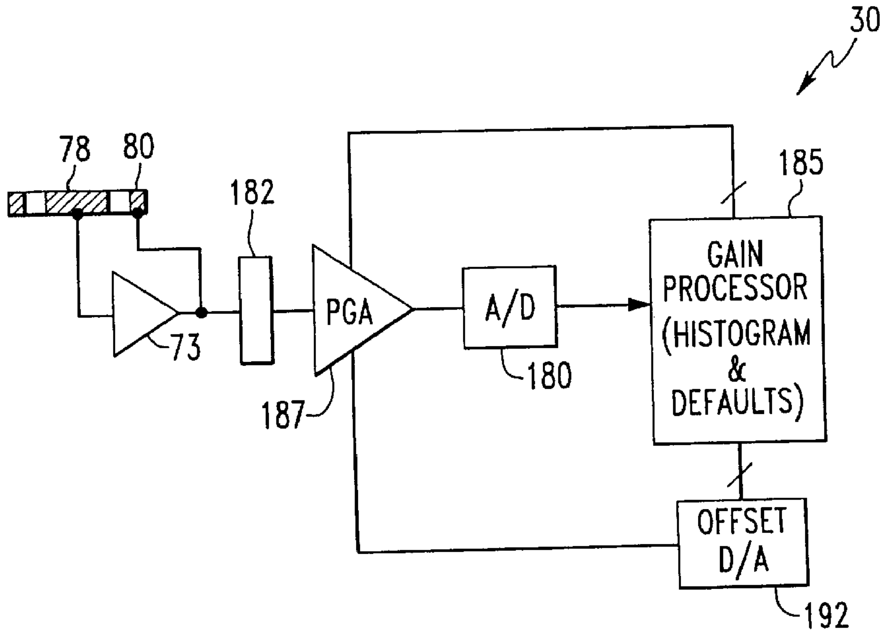
30
78
80
185
182
GAIN PROCESSOR (HISTOGRAM & DEFAULTS)
PGA
A/D
73
180
187
OFFSET D/A
192

FIG. 13

FINGERPRINT SENSOR WITH GAIN CONTROL FEATURES AND ASSOCIATED METHODS

FIELD OF THE INVENTION

The present invention relates to the field of personal identification and verification, and, more particularly, to the field of fingerprint sensing and processing.

BACKGROUND OF THE INVENTION

Fingerprint sensing and matching is a reliable and widely used technique for personal identification or verification. In particular, a common approach to fingerprint identification involves scanning a sample fingerprint or an image thereof and storing the image and/or unique characteristics of the fingerprint image. The characteristics of a sample fingerprint may be compared to information for reference fingerprints already in a database to determine proper identification of a person, such as for verification purposes.

A typical electronic fingerprint sensor is based upon illuminating the finger surface using visible light, infrared light, or ultrasonic radiation. The reflected energy is captured with some form of camera, for example, and the resulting image is framed, digitized and stored as a static digital image. For example, U.S. Pat. No. 4,210,899 to Swonger et al. discloses an optical scanning fingerprint reader cooperating with a central processing station for a secure access application, such as admitting a person to a location or providing access to a computer terminal. U.S. Pat. No. 4,525,859 to Bowles similarly discloses a video camera for capturing a fingerprint image and uses the minutiae of the fingerprints, that is, the branches and endings of the fingerprint ridges, to determine a match with a database of reference fingerprints.

Unfortunately, optical sensing may be affected by stained fingers or an optical sensor may be deceived by presentation of a photograph or printed image of a fingerprint rather than a true live fingerprint. In addition, optical schemes may require relatively large spacings between the finger contact surface and associated imaging components. Moreover, such sensors typically require precise alignment and complex scanning of optical beams. Accordingly, optical sensors may thus be bulky and be susceptible to shock, vibration and surface contamination. Accordingly, an optical fingerprint sensor may be unreliable in service in addition to being bulky and relatively expensive due to optics and moving parts.

U.S. Pat. No. 4,353,056 to Tsikos discloses another approach to sensing a live fingerprint. In particular, the patent discloses an array of extremely small capacitors located in a plane parallel to the sensing surface of the device. When a finger touches the sensing surface and deforms the surface, a voltage distribution in a series connection of the capacitors may change. The voltages on each of the capacitors is determined by multiplexor techniques. Unfortunately, the resilient materials required for the sensor may suffer from long term reliability problems. In addition, multiplexing techniques for driving and scanning each of the individual capacitors may be relatively slow and cumbersome. Moreover, noise and stray capacitances may adversely affect the plurality of relatively small and closely spaced capacitors.

U.S. Pat. No. 5,325,442 to Knapp discloses a fingerprint sensor including a plurality of sensing electrodes. Active addressing of the sensing electrodes is made possible by the provision of a switching device associated with each sensing

electrode. A capacitor is effectively formed by each sensing electrode in combination with the respective overlying portion of the finger surface which, in turn, is at ground potential. The sensor may be fabricated using semiconductor wafer and integrated circuit technology. The dielectric material upon which the finger is placed may be provided by silicon nitride or a polyimide which may be provided as a continuous layer over an array of sensing electrodes. Further conductors may be provided on the surface of the dielectric material remote from the sensing electrodes and extending over regions between the sensing electrodes, for example, as lines or in grid form, which conductors are grounded in order to improve the electrical contact to the finger surface.

Unfortunately, driving the array of closely spaced sensing electrodes as disclosed in the Knapp et al. patent may be difficult since adjacent electrodes may affect one another. Another difficulty with such a sensor may be its ability to distinguish ridges and valleys of a fingerprint when the conductivity of the skin and any contaminants may vary widely from person-to-person and even over a single fingerprint. Yet another difficulty with such a sensor, as with many optical sensors, is that different portions of the fingerprint may require relatively complicated post image collection processing to provide for usable signal levels and contrast to thereby permit accurate determination of the ridges and valleys of the fingerprint. For example, U.S. Pat. No. 4,811,414 to Fishbine et al. discloses methods for noise averaging, illumination equalizing, directional filtering, curvature correcting, and scale correcting for an optically generated fingerprint image. Unfortunately, the various processing steps are complex and require considerable computational power in a downstream processor. Signal processing of other fingerprint circuits may also be relatively complicated and therefore expensive and/or slow.

Greater advances in fingerprint sensing and matching for identification and verification are desirable for many applications. Unfortunately, current sensors and their associated circuitry may be too bulky, expensive and unreliable for a great many applications which would otherwise benefit from fingerprint identification and verification technology. In addition, fingerprint images generated by conventional sensors may vary considerably from individual-to-individual and for different sensing conditions. In addition, process variations in manufacturing may cause sensors to vary considerably from one to another. Accordingly, consistent results may be very difficult when using a conventional fingerprint sensor.

SUMMARY OF THE INVENTION

In view of the foregoing background, it is therefore an object of the present invention to provide a fingerprint sensor and related methods so that the fingerprint sensor may accommodate variations in image signal intensities, such as between different fingers, for different sensing conditions, or based on manufacturing process variations, for example.

This and other objects, features and advantages in accordance with the present invention are provided by a fingerprint sensor including an array of fingerprint sensing elements; analog-to-digital (A/D) conversion means having a controllable range; scanning means to perform sequential A/D conversions of predetermined ones of the array of fingerprint sensing elements; and range determining and setting means for controlling the range of the A/D conversion means based upon prior A/D conversions to thereby provide enhanced conversion resolution. The conversion

resolution is enhanced despite variations in sensed fingers, conditions, or despite process variations resulting from manufacturing.

In one embodiment, the A/D conversion means preferably comprises a plurality or bank of A/D converters for simultaneously converting analog signals from a corresponding plurality of fingerprint sensing elements. By enabling dynamic exploitation of the full resolution range of the A/D converters, the accuracy of the sensing can be significantly improved.

The A/D conversion means may comprise at least one reference voltage input for permitting setting of the range. Accordingly, the range determining and setting means may comprise a processor, and at least one digital-to-analog converter connected between the processor and the at least one reference voltage input. In particular, the A/D converters may typically include a first reference voltage input and a second reference voltage input for setting corresponding first and second range points thereby defining the range. Alternately, or in addition thereto, the A/D conversion means may include at least one amplifier having a controllable gain for permitting setting of the range.

The range determining and setting means may comprise histogram generating means for generating a histogram based upon prior A/D conversions. In addition, the range determining and setting means may comprise default setting means for setting a default range for initial ones of the fingerprint sensing elements.

Each of the fingerprint sensing elements may be provided by an electric field sensing electrode and an amplifier associated therewith. A shield electrode amy also be associated with each electric field sensing electrode and be connected to a respective amplifier.

A method aspect of the invention is for operating a fingerprint sensor of a type comprising an array of fingerprint sensing elements. The method preferably comprises the steps of: converting analog signals from the array of fingerprint sensing elements to digital signals using A/D converters having a controllable range; performing sequential A/D conversions of predetermined ones of the array of fingerprint sensing elements; and controlling the range of the A/D converters based upon prior A/D conversions to thereby provide enhanced conversion resolution.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a top plan view of a fingerprint sensor in accordance with the present invention.

FIG. **2** is a schematic view of a circuit portion of the fingerprint sensor as shown in FIG. **1**.

FIG. **3** is a greatly enlarged top plan view of the sensing portion of the fingerprint sensor as shown in FIG. **1**.

FIG. **4** is a schematic diagram of another circuit portion of the fingerprint sensor as shown in FIG. **1**.

FIG. **5** is a greatly enlarged side cross-sectional view of a portion of the fingerprint sensor as shown in FIG. **1**.

FIG. **6** is a greatly enlarged side cross-sectional view of a portion of an alternate embodiment of the fingerprint sensor in accordance with the invention.

FIG. **7** is a greatly enlarged side cross-sectional view of another portion of the fingerprint sensor as shown in FIG. **1**.

FIG. **8** is a schematic block diagram of yet another circuit portion of the fingerprint sensor as shown in FIG. **1**.

FIG. **9** is a schematic circuit diagram of a portion of the circuit as shown in FIG. **8**.

FIG. **10** is a schematic block diagram of still another circuit portion of the fingerprint sensor as shown in FIG. **1**.

FIG. **11** is a schematic block diagram of an alternate embodiment of the circuit portion shown in FIG. **10**.

FIG. **12** is a schematic block diagram of an additional circuit portion of the fingerprint sensor as shown in FIG. **1**.

FIG. **13** is a schematic block diagram of an alternate embodiment of the circuit portion shown in FIG. **12**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout. The scaling of various features, particularly layers in the drawing figures, have been exaggerated for clarity of explanation.

Referring to FIGS. **1–3**, the fingerprint sensor **30** in accordance with the invention is initially described. The illustrated sensor **30** includes a housing or package **51**, a dielectric layer **52** exposed on an upper surface of the package which provides a placement surface for the finger, and a plurality of output pins, not shown. A first conductive strip or external electrode **54** around the periphery of the dielectric layer **52**, and a second external electrode **53** provide contact electrodes for the finger **79** as described in greater detail below. The sensor **30** may provide output signals in a range of sophistication levels depending on the level of processing incorporated in the package as would be readily understood by those skilled in the art.

The sensor **30** includes a plurality of individual pixels or sensing elements **30***a* arranged in array pattern as perhaps best shown in FIG. **3**. As would be readily understood by those skilled in the art, these sensing elements are relatively small so as to be capable of sensing the ridges **59** and intervening valleys **60** of a typical fingerprint. As will also be readily appreciated by those skilled in the art, live fingerprint readings as from the electric field sensor **30** in accordance with the present invention may be more reliable than optical sensing, because the impedance of the skin of a finger in a pattern of ridges and valleys is extremely difficult to simulate. In contrast, an optical sensor may be deceived by a photograph or other similar image of a fingerprint, for example.

The sensor **30** includes a substrate **65**, and one or more active semiconductor devices formed thereon, such as the schematically illustrated amplifier **73**. A first metal layer **66** interconnects the active semiconductor devices. A second or ground plane electrode layer **68** is above the first metal layer **66** and separated therefrom by an insulating layer **67**. A third metal layer **71** is positioned over another dielectric layer **70**. In the illustrated embodiment, the first external electrode **54** is connected to an excitation drive amplifier **74** which, in turn, drives the finger **79** with a signal may be typically in the range of about 1 KHz to 1 MHz. Accordingly, the drive or excitation electronics are thus relatively uncomplicated and the overall cost of the sensor **30** may be relatively low, while the reliability is great.

An illustratively circularly shaped electric field sensing electrode **78** is on the insulating layer **70**. The sensing

electrode **78** may be connected to sensing integrated electronics, such as the illustrated amplifier **73** formed adjacent the substrate **65** as schematically illustrated, and as would be readily appreciated by those skilled in the art.

An annularly shaped shield electrode **80** surrounds the sensing electrode **78** in spaced relation therefrom. As would be readily appreciated by those skilled in the art, the sensing electrode **78** and its surrounding shield electrode **80** may have other shapes, such as hexagonal, for example, to facilitate a close packed arrangement or array of pixels or sensing elements **30***a*. The shield electrode **80** is an active shield which is driven by a portion of the output of the amplifier **73** to help focus the electric field energy and, moreover, to thereby reduce the need to drive adjacent electric field sensing electrodes **78**.

The sensor **30** includes only three metal or electrically conductive layers **66, 68** and **71**. The sensor **30** can be made without requiring additional metal layers which would otherwise increase the manufacturing cost, and, perhaps, reduce yields. Accordingly, the sensor **30** is less expensive and may be more rugged and reliable than a sensor including four or more metal layers as would be appreciated by those skilled in the art.

Another important aspect of the present invention is that the amplifier **73** may be operated at a gain of greater than about one to drive the shield electrode **80**. Stability problems do not adversely affect the operation of the amplifier **73**. Moreover, the common mode and general noise rejection are greatly enhanced according to this feature of the invention. In addition, the gain greater than one tends to focus the electric field with resect to the sensing electrode **78** as will be readily appreciated by those skilled in the art.

In general, the sensing elements **30***a* operate at very low currents and at very high impedances. For example, the output signal from each sensing electrode **78** is desirably about 5 to 10 millivolts to reduce the effects of noise and permit further processing of the signals. The approximate diameter of each sensing element **30***a*, as defined by the outer dimensions of the shield electrode **80,** may be about 0.002 to 0.005 inches in diameter. The ground plane electrode **68** protects the active electronic devices from unwanted excitation. The various signal feedthrough conductors for the electrodes **78, 80** to the active electronic circuitry may be readily formed as would be understood by those skilled in the art.

The overall contact or sensing surface for the sensor **30** may desirably be about 0.5 by 0.5 inches—a size which may be readily manufactured and still provide a sufficiently large surface for accurate fingerprint sensing and identification. The sensor **30** in accordance with the invention is also fairly tolerant of dead pixels or sensing elements **30***a*. A typical sensor **30** includes an array of about 256 by 256 pixels or sensor elements, although other array sizes are also contemplated by the present invention. The sensor **30** may also be fabricated at one time using primarily conventional semiconductor manufacturing techniques to thereby significantly reduce the manufacturing costs.

Turning now additionally to FIG. **4**, another aspect of the sensor **30** of the invention is described. The sensor may include power control means for controlling operation of active circuit portions **100** based upon sensing finger contact with the first external electrode **54** as determined by the illustrated finger sense block or circuit **101**. For example, the finger sense circuit **101** may operate based upon a change in impedance to an oscillator to thereby determine finger contact. Of course, other approaches for sensing contact with the finger are also contemplated by the invention. The power control means may include wake-up means for only powering active circuit portions upon sensing finger contact with the first external electrode to thereby conserve power. Alternately or additionally, the power control means may further comprise protection means for grounding active circuit portions upon not sensing finger contact with the first external electrode. In the illustrated embodiment, a combination of wake-up and protection controller circuits **101** are illustrated.

Moreover, the fingerprint sensor **30** may further comprise finger charge bleed means for bleeding a charge from a finger or other object upon contact therewith. The finger charge bleed means may be provided by the second external electrode **53** carried by the package **51** for contact by a finger, and a charge bleed resistor **104** connected between the second external electrode and an earth ground. As schematically illustrated in the upper right hand portion of FIG. **4**, the second electrode may alternately be provided by a movable electrically conductive cover **53**' slidably connected to the package **51** for covering the opening to the exposed upper dielectric layer **52**. A pivotally connected cover is also contemplated by the present invention. Accordingly, under normal conditions, the charge would be bled from the finger as the cover **53'** is moved to expose the sensing portion of the sensor **30**.

In addition, the finger charge bleed means and power control means may be such that the active portions remain grounded until the charge bleed means can remove the charge on the finger before powering the active circuit portions, such as by providing a brief delay during wake-up sufficient to permit the charge to be discharged through the resistor **104** as would be readily understood by those skilled in the art. Accordingly, power may be conserved in the sensor **30** and ESD protection provided by the sensor so that the sensor is relatively inexpensive, yet robust and conserves power.

Referring now additionally to FIG. **5** yet another significant feature of the sensor **30** is described. The dielectric covering **52** may preferably comprise a z-axis anisotropic dielectric layer **110** for focussing an electric field, shown by the illustrated field lines, at each of the electric field sensing electrodes **78**. In other words, the dielectric layer **110** may be relatively thick, but not result in defocussing of the electric fields propagating therethrough because of the z-axis anisotropy of the material. Typically there would be a trade-off between field focus and mechanical protection. Unfortunately, a thin film which is desirable for focussing, may permit the underlying circuit to be more easily subject to damage.

The z-axis anisotropic dielectric layer **110** of the present invention, for example, may have a thickness in range of about 0.0001 to 0.004 inches. Of course, the z-axis anisotropic dielectric layer **110** is also preferably chemically resistant and mechanically strong to withstand contact with fingers, and to permit periodic cleanings with solvents. The z-axis anisotropic dielectric layer **110** may preferably define an outermost protective surface for the integrated circuit die **120**. Accordingly, the overall dielectric covering **52** may further include at least one relatively thin oxide, nitride, carbide, or diamond layer **111** on the integrated circuit die **120** and beneath the z-axis anisotropic dielectric layer **110**. The thin layer **111** will typically be relatively hard, and the z-axis anisotropic dielectric layer **110** is desirably softer to thereby absorb more mechanical activity.

The z-axis anisotropic dielectric layer **110** may be provided by a plurality of oriented dielectric particles in a cured

matrix. For example, the z-axis anisotropic dielectric layer **110** may comprise barium titanate in a polyimide matrix. Those of skill in the art will appreciate other materials exhibiting z-axis anisotropy suitable for the present invention. For example, certain ceramics exhibit dielectric anisotropy as would also be appreciated by those skilled in the art.

Turning to FIG. **6**, another variation of a z-axis dielectric covering **52**' is schematically shown by a plurality of high dielectric portions **112** aligned with corresponding electric field sensing electrodes **78**, and a surrounding matrix of lower dielectric portions **113**. This embodiment of the dielectric covering **52**' may be formed in a number of ways, such as by forming a layer of either the high dielectric or low dielectric portions, selectively etching same, and filling the openings with the opposite material. Another approach may be to use polarizable microcapsules and subjecting same to an electric field during curing of a matrix material. A material may be compressed to cause the z-axis anisotropy. Laser and other selective processing techniques may also be used as would be readily understood by those skilled in the art.

Another aspect of the invention relates to being able to completely cover and protect the entire upper surface of the integrated circuit die **120**, and still permit connection and communication with the external devices and circuits as now further explained with reference to FIG. **7**. The third metal layer **71** (FIG. **2**) preferably further includes a plurality of capacitive coupling pads **116***a*–**118***a* for permitting capacitive coupling of the integrated circuit die **120**. Accordingly, the dielectric covering **52** is preferably continuous over the capacitive coupling pads **116***a*–**118***a* and the array of electric field sensing electrodes **78** of the pixels **30***a* (FIG. **1**). In sharp contrast to this feature of the present invention, it is conventional to create openings through an outer coating to electrically connect to the bond pads. Unfortunately, these openings would provide pathways for water and/or other contaminants to come in contact with and damage the die.

A portion of the package **51** includes a printed circuit board **122** which carries corresponding pads **115***b*–**118***b*. A power modulation circuit **124** is coupled to pads **115***b*–**116***b*, while a signal modulation circuit **126** is illustrative coupled to pads **117***b*–**118***b*. As would be readily understood by those skilled in the art, both power and signals may be readily coupled between the printed circuit board **122** and the integrated circuit die **120**, further using the illustrated power demodulation/regulator circuit **127**, and the signal demodulation circuit **128**. The z-axis anisotropic dielectric layer **110** also advantageously reduces cross-talk between adjacent capacitive coupling pads. This embodiment of the invention **30** presents no penetrations through the dielectric covering **52** for moisture to enter and damage the integrated circuit die **120**. In addition, another level of insulation is provided between the integrated circuit and the external environment.

For the illustrated fingerprint sensor **30**, the package **51** preferably has an opening aligned with the array of electric field sensing electrodes **78** (FIGS. **1**–**3**). The capacitive coupling and z-axis anisotropic layer **110** may be advantageously used in a number of applications in addition to the illustrated fingerprint sensor **30**, and particularly where it is desired to have a continuous film covering the upper surface of the integrated circuit die **120** and pads **116***a*–**118***a*.

Further aspects of the manufacturing of the sensor **30** including the z-axis anisotropic dielectric material are explained in U.S. patent application, Ser. No. 08/857,525, filed May 16, 1997, entitled "Direct Chip Attachment Method and Devices Produced Thereby". This patent application has attorney work docket no. 18763, is assigned to the present assignee, and the entire disclosure of which is incorporated herein by reference.

Referring additionally to FIGS. **8** and **9**, impedance matrix filtering aspects of the invention are now described. As shown in FIG. **8**, the fingerprint sensor **30** may be considered as comprising an array of fingerprint sensing elements **130** and associated active circuits **131** for generating signals relating to the fingerprint image. The illustrated sensor **30** also includes an impedance matrix **135** connected to the active circuits for filtering the signals therefrom.

As shown with more particular reference to FIG. **9**, the impedance matrix **135** includes a plurality of impedance elements **136** with a respective impedance element connectable between each active circuit of a respective fingerprint sensing element as indicated by the central node **138**, and the other active circuits (outer nodes **140**). The impedance matrix **135** also includes a plurality of switches **137** with a respective switch connected in series with each impedance element **136**. An input signal may be supplied to the central node **138** via the illustrated switch **142** and its associated impedance element **143**. The impedance element may one or more of a resistor as illustrated, and a capacitor **134** as would be readily appreciated by those skilled in the art.

Filter control means may operate the switches **137** to perform processing of the signals generated by the active circuits **131**. In one embodiment, the fingerprint sensing elements **130** may be electric field sensing electrodes **78**, and the active circuits **131** may be amplifiers **73** (FIG. **2**). Of course other sensing elements and active circuits may also benefit from the impedance matrix filtering of the present invention as would be readily understood by those skilled in the art.

Ridge flow determining means **145** may be provided for selectively operating the switches **137** of the matrix **135** to determine ridge flow directions of the fingerprint image. More particularly, the ridge flow determining means **145** may selectively operate the switches **137** for determining signal strength vectors relating to ridge flow directions of the fingerprint image. As would be readily understood by those skilled in the art, the ridge flow directions may be determined based upon well known rotating slit principles.

The sensor **30** may include core location determining means **146** cooperating with the ridge flow determining means **145** for determining a core location of the fingerprint image. The position of the core is helpful, for example, in extracting and processing minutiae from the fingerprint image as would also be readily understood by those skilled in the art.

As also schematically illustrated in FIG. **8**, a binarizing filter **150** may be provided for selectively operating the switches **137** to convert a gray scale fingerprint image to a binarized fingerprint image. Considered another way, the impedance matrix **135** may be used to provide dynamic image contrast enhancement. In addition, an edge smoothing filter **155** may be readily implemented to improve the image. As also schematically illustrated other spatial filters **152** may also be implemented using the impedance matrix **135** for selectively operating the switches **137** to spatially filter the fingerprint image as would be readily appreciated by those of skill in the art. Accordingly, processing of the fingerprint image may be carried out at the sensor **30** and thereby reduce additional downstream computational requirements.

As shown in the illustrated embodiment of FIG. **9**, the impedance matrix **135** may comprise a plurality of impedance elements with a respective impedance element **136**

connectable between each active circuit for a given fingerprint sensing element **130** and eight other active circuits for respective adjacent fingerprint sensing elements.

Yet another aspect of the invention is the provision of control means **153** for sequentially powering sets of active circuits **131** to thereby conserve power. Of course, the respective impedance elements **136** are desirably also sequentially connected to perform the filtering function. The powered active circuits **131** may be considered as defining a cloud or kernel as would be readily appreciated by those skilled in the art. The power control means **153** may be operated in an adaptive fashion whereby the size of the area used for filtering is dynamically changed for preferred image characteristics as would also be readily understood by those skilled in the art. In addition, the power control means **153** may also power only certain ones of the active circuits corresponding to a predetermined area of the array of sensing elements **130**. For example, every other active circuit **131** could be powered to thereby provide a larger area, but reduced power consumption as would also be understood by those skilled in the art.

Reader control means **154** may be provided to read only predetermined subsets of each set of active circuits **131** so that a contribution from adjacent active circuits is used for filtering. In other words, only a subset of active circuits **131** are typically simultaneously read although adjacent active circuits **131** and associated impedance elements **136** are also powered and connected, respectively. For example, 16 impedance elements **136** could define a subset and be readily simultaneously read. The subset size could be optimized for different sized features to be determined as would be readily appreciated by those skilled in the art.

Accordingly, the array of sense elements **130** can be quickly read, and power consumption substantially reduced since all of the active circuits **131** need not be powered for reading a given set of active circuits. For a typical sensor, the combination of the power control and impedance matrix features described herein may permit power savings by a factor of about 10 as compared to powering the full array.

It is another important advantage of the fingerprint sensor **30** according to present invention to guard against spoofing or deception of the sensor into incorrectly treating a simulated image as a live fingerprint image. For example, optical sensors may be deceived or spoofed by using a paper with a fingerprint image thereon. The unique electric field sensing of the fingerprint sensor **30** of the present invention provides an effective approach to avoiding spoofing based upon the complex impedance of a finger.

As shown in FIG. **10**, the fingerprint sensor **30** may be considered as including an array of impedance sensing elements **160** for generating signals related to a finger **79** or other object positioned adjacent thereto. In the embodiment described herein, the impedance sensing elements **160** are provided by electric field sensing electrodes **78** and amplifiers **73** (FIG. **2**) associated therewith. In addition, a guard shield **80** may be associated with each electric field sensing electrode **78** and connected to a respective amplifier **73**. Spoof reducing means **161** is provided for determining whether or not an impedance of the object positioned adjacent the array of impedance sensing elements **160** corresponds to a live finger **79** to thereby reduce spoofing of the fingerprint sensor by an object other than a live finger. A spoofing may be indicated, such as by the schematically illustrated lamp **163** and/or used to block further processing. Alternately, a live fingerprint determination may also be indicated by a lamp **164** and/or used to permit further processing of the fingerprint image as will be readily appreciated by those skilled in the art. Many other options for indicating a live fingerprint or an attempted spoofing will be readily appreciated by those skilled in the art.

In one embodiment, the spoof reducing means **161** may include impedance determining means **165** to detect a complex impedance having a phase angle in a range of about 10 to 60 degrees corresponding to a live finger **79**. Alternately, the spoof reducing means **161** may detect an impedance having a phase angle of about 0 degrees corresponding to some objects other than a live finger, such as a sheet of paper having an image thereon, for example. In addition, the spoof reducing means **161** may detect an impedance of 90 degrees corresponding to other objects.

Turning now to FIG. **11**, another embodiment of spoof reducing means is explained. The fingerprint sensor **30** may preferably includes drive means for driving the array of impedance sensing elements **160**, such as the illustrated excitation amplifier **74** (FIG. **2**). The sensor also includes synchronous demodulator means **170** for synchronously demodulating signals from the array of impedance sensing elements **160**. Accordingly, in one particularly advantageous embodiment of the invention, the spoof reducing means comprises means for operating the synchronous demodulator means **170** at at least one predetermined phase rotation angle. For example, the synchronous demodulator means **170** could be operated in a range of about 10 to 60 degrees, and the magnitude compared to a predetermined threshold indicative of a live fingerprint. A live fingerprint typically has a complex impedance within the range of 10 to 60 degrees.

Alternately, ratio generating and comparing means **172** may be provided for cooperating with the synchronous demodulator means **170** for synchronously demodulating signals at first and second phase angles θ_1, θ_2, generating an amplitude ratio thereof, and comparing the amplitude ratio to a predetermined threshold to determine whether the object is a live fingerprint or other object. Accordingly, the synchronous demodulator **170** may be readily used to generate the impedance information desired for reducing spoofing of the sensor **30** by an object other than a live finger. The first angle θ_1 and the second θ_2 may have a difference in a range of about 45 to 90 degrees, for example. Other angles are also contemplated by the invention as would be readily appreciated by those skilled in the art.

The fingerprint sensor **30** also includes an automatic gain control feature to account for a difference in intensity of the image signals generated by different fingers or under different conditions, and also to account for differences in sensor caused by process variations. It is important for accurately producing a fingerprint image, that the sensor can discriminate between the ridges and valleys of the fingerprint. Accordingly, the sensor **30** includes a gain control feature, a first embodiment of which is understood with reference to FIG. **12**.

As shown in FIG. **12**, the illustrated portion of the fingerprint sensor **30** includes an array of fingerprint sensing elements in the form of the electric field sensing electrodes **78** and surrounding shield electrodes **80** connected to the amplifiers **73**. Other fingerprint sensing elements may also benefit from the following automatic gain control implementations as will be appreciated by those skilled in the art.

The signal processing circuitry of the sensor **30** preferably includes a plurality of analog-to-digital (A/D) converters **180** as illustrated. Moreover, each of these A/D converters **180** may have a controllable scale. Scanning means **182**

sequentially connects different elements to the bank of A/D converters **180**. The illustrated gain processor **185** provides range determining and setting means for controlling the range of the A/D converters **180** based upon prior A/D conversions to thereby provide enhanced conversion resolution. The A/D converters **180** may comprise the illustrated reference voltage input V_{ref} and offset voltage input V_{offset} for permitting setting of the range as would be readily appreciated by those skilled in the at. Accordingly, the range determining and setting means may also comprise a first digital-to-analog D/A converter **186** connected between the gain processor **185** and the reference voltage V_{ref} inputs of the A/D converters **180** as would also be readily understood by those skilled in the art. In addition, a second D/A converter **189** is also illustratively connected to the offset voltage inputs V_{offset} from the gain processor **185**.

The gain processor **185** may comprise histogram generating means for generating a histogram, as described above, and based upon prior A/D conversions. The graph adjacent the gain processor **185** in FIG. **12** illustrates a typical histogram plot **191**. The histogram plot **191** includes two peaks corresponding to the sensed ridges and valleys of the fingerprint as would be readily appreciated by those skilled in the art. By setting the range for the A/D converters **180,** the peaks can be readily positioned as desired to thereby account for the variations discussed above and use the full resolution of the A/D converters **180**.

Turning additionally to FIG. **13**, the A/D converters **180** may include an associated input amplifier for permitting setting of the range. In this variation, the range determining and setting means may also comprise the illustrated gain processor **185**, and wherein the amplifier is a programmable gain amplifier (PGA) **187** connected to the processor. A digital word output from the gain processor **185** sets the gain of the PGA **187** so that full use of the resolution of the A/D converters **180** is obtained for best accuracy. A second digital word output from the gain processor **185** and coupled to the amplifier **187** through the illustrated D/A converter **192** may also control the offset of the amplifier as would also be readily appreciated by those skilled in the art.

The range determining and setting means of the gain processor **185** may comprise default setting means for setting a default range for initial ones of the fingerprint sensing elements. The automatic gain control feature of the present invention allows the D/A converters **180** to operate over their full resolution range to thereby increase the accuracy of the image signal processing.

Other aspects, advantages, and features relating to sensing of fingerprints are disclosed in copending U.S. patent application Ser. No. 08/592,469 entitled "Electric Field Fingerprint Sensor and Related Methods", and U.S. patent application Ser. No. 08/671,430 entitled "Integrated Circuit Device Having an Opening Exposing the Integrated Circuit Die and Related Methods", both assigned to the assignee of the present invention, and the entire disclosures of which are incorporated herein by reference. In addition, many modifications and other embodiments of the invention will come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed, and that modifications and embodiments are intended to be included within the scope of the appended claims.

That which is claimed is:

1. A fingerprint sensor to enhance conversion resolution of ridges and valleys of sensed fingerprints, the fingerprint sensor comprising:

an array of fingerprint sensing elements, each element comprising an electric field sensing electrode and an amplifier associated therewith;

analog-to-digital (A/D) conversion means having a controllable range and for converting analog signals from said array of fingerprint sensing elements to digital signals based upon the range;

scanning means responsive to said array of fingerprint sensing elements and positioned in communication with said A/D conversion means for operating said A/D conversion means and said array of fingerprint sensing elements to perform sequential A/D conversions of predetermined ones of said array of fingerprint sensing elements; and

range determining and setting means responsive to each said A/D conversion means for controlling the range of said A/D conversion means based upon a plurality of the sequential A/D conversions performed by said A/D conversion means to thereby provide enhanced conversion resolution of ridges and valleys of sensed fingerprints.

2. A fingerprint sensor according to claim **1** wherein said A/D conversion means comprises a plurality of A/D converters for simultaneously converting analog signals from a corresponding plurality of fingerprint sensing elements.

3. A fingerprint sensor according to claim **1** wherein said A/D conversion means comprises at least one range input for permitting setting of at least one range point; and wherein said range determining and setting means comprises a processor, and at least one digital-to-analog converter connected between said processor and said at least one range input.

4. A fingerprint sensor according to claim **1** wherein said A/D conversion means comprises a first reference voltage input for permitting setting of a first range point.

5. A fingerprint sensor according to claim **4** wherein said A/D conversion means further comprises a second reference voltage input for permitting setting of a second range point.

6. A fingerprint sensor according to claim **1** wherein said A/D conversion means comprises at least one amplifier for permitting setting of the range.

7. A fingerprint sensor according to claim **1** wherein said range determining and setting means comprises histogram generating means for generating a histogram based upon the plurality of sequential A/D conversions.

8. A fingerprint sensor according to claim **1** wherein said range determining and setting means comprises default setting means for setting a default range for initial ones of said fingerprint sensing elements.

9. A fingerprint sensor according to claim **1** further comprising a shield electrode associated with each electric field sensing electrode and connected to a respective amplifier.

10. A fingerprint sensor to enhance conversion resolution of ridges and valleys of sensed fingerprints, the fingerprint sensor comprising:

an array of fingerprint sensing elements, each element comprising an electric field sensing electrode and an amplifier associated therewith;

at least one analog-to-digital (A/D) converter having at least one reference voltage input and for converting an analog signal from at least one fingerprint sensing element to a digital signal based upon the at least one reference voltage;

scanning means responsive to said array of fingerprint sensing elements and positioned in communication

with said at least one A/D converter for operating said at least one A/D converter and said array of fingerprint sensing elements to perform sequential A/D conversions of predetermined ones of said array of fingerprint sensing elements; and

reference voltage determining and setting means responsive to said at least one A/D converter for controlling the at least one reference voltage of said at least one A/D converter based upon a plurality of the sequential A/D conversions performed by said A/D conversion means to thereby provide enhanced conversion resolution of ridges and valleys of sensed fingerprints.

11. A fingerprint sensor according to claim **10** wherein said at least one A/D converter comprises a plurality of A/D converters for simultaneously converting analog signals from a corresponding plurality of fingerprint sensing elements.

12. A fingerprint sensor according to claim **10** wherein said reference voltage determining and setting means comprises a processor, and at least one digital-to-analog converter connected between said processor and said at least one reference voltage input.

13. A fingerprint sensor according to claim **10** further comprising at least one amplifier cooperating with said at least one A/D converter for permitting setting of the range thereof.

14. A fingerprint sensor according to claim **10** wherein said reference voltage determining and setting means comprises histogram generating means for generating a histogram based upon the plurality of sequential A/D conversions.

15. A fingerprint sensor according to claim **10** wherein said reference voltage determining and setting means comprises default setting means for setting at least one default reference voltage for initial ones of said fingerprint sensing elements.

16. A fingerprint sensor according to claim **10** further comprising a shield electrode associated with each electric field sensing electrode and connected to a respective amplifier.

17. A fingerprint sensor to enhance conversion resolution of ridges and valleys of sensed fingerprints, the fingerprint sensor comprising:

an array of fingerprint sensing elements, each element comprising an electric field sensing electrode and an amplifier associated therewith;

a plurality of analog-to-digital (A/D) converters each having at least one reference voltage input and for converting an analog signal from at least one fingerprint sensing element to a digital signal based upon the at least one reference voltage;

scanning means responsive to said array of fingerprint sensing elements and in communication with said plurality of A/D converters for operating said plurality of A/D converters and said array of fingerprint sensing elements to perform sequential A/D conversions of predetermined ones of said array of fingerprint sensing elements; and

reference voltage determining and setting means responsive to said plurality of A/D converters for controlling the at least one reference voltage of each of said plurality of A/D converters based upon a plurality of the sequential A/D conversions performed by said plurality of A/D converters to thereby provide enhanced conversion resolution of ridges and valleys of sensed fingerprints, said reference voltage determining and setting means comprising histogram generating means for generating a histogram based upon the plurality of the sequential A/D conversions.

18. A fingerprint sensor according to claim **17** wherein said reference voltage determining and setting means comprises a processor, and at least one digital-to-analog converter connected between said processor and said at least one reference voltage input.

19. A fingerprint sensor according to claim **17** further comprising a respective amplifier cooperating with each A/D converter for permitting setting of the range thereof.

20. A fingerprint sensor according to claim **17** wherein said reference voltage determining and setting means comprises default setting means for setting at least one default reference voltage for initial ones of said fingerprint sensing elements.

21. A fingerprint sensor according to claim **17** further comprising a shield electrode associated with each electric field sensing electrode and connected to a respective amplifier.

22. A method for sensing fingerprints using an array of fingerprint sensing elements, each element comprising an electric field sensing electrode and an amplifier associated therewith, to enhance conversion resolution of ridges and valleys of the sensed fingerprints, the method comprising the steps of:

sequentially converting analog signals from predetermined ones of the array of fingerprint sensing elements to digital signals using at least one A/D converter having a controllable range; and

determining and controlling the range of the at least one A/D converter based upon a plurality of the performed sequential A/D conversions performed by the at least one A/D converter to thereby provide enhanced conversion resolution of ridges and valleys of sensed fingerprints.

23. A method according to claim **22** wherein the range of the at least one A/D converter is controllable based upon at least one reference voltage; and wherein the step of determining and controlling the range comprises controlling the at least one reference voltage.

24. A method according to claim **22** wherein the step of converting analog signals comprises converting same using at least one amplifier having a controllable gain for permitting setting of the range; and wherein the step of determining and controlling the range comprises controlling the range using the amplifier.

25. A method according to claim **22** wherein the step of determining and controlling the range comprises generating a histogram based upon the plurality of sequential A/D conversions.

26. A method according to claim **22** wherein the step of determining and controlling the range comprises setting a default range for initial ones of the fingerprint sensing elements.

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